Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies	)))))	ET Docket No. 03-108
	)	
Authorization and Use of Software Defined Radios	))	ET Docket No. 00-47 (Terminated)

COMMENTS OF
THOMAS W. HAZLETT
AND
MATTHEW L. SPITZER

May 3, 2004

1. In this Notice of Proposed Rulemaking and Order (NPRM),[1] the Federal Communications Commission considers rule changes for cognitive radios. This is an attempt to create "opportunities for flexible, efficient, and reliable spectrum use," as the docket characterizes itself, but policies that would actually enable such outcomes are considered scarcely at all. In a recent proceeding to consider establishment of an Interference Temperature,[2] we submitted a White Paper at the behest of Verizon Communications. Because many of the analytical issues in that proceeding are directly relevant to the Cognitive Radio NPRM, we attach a copy of Thomas W. Hazlett and Matthew L. Spitzer, *Advanced Wireless Services, Spectrum Sharing, and the Economics of an "Interference Temperature,"* to this Comment.[3]

2. Cognitive radios are among the family of technologies that attempt to use multiple spectrum spaces (defined in time, frequency, or power) to increase communications output. The use of such systems conflicts with the basic structure of FCC spectrum regulation: block allocation. Smart radios attempt to skip around, discovering where additional throughput might be achieved at relatively low cost (in terms of the conflicts created for other users). Depending on the economics of such applications – *i.e.*, the value of the new services, the cost of the new systems, and the value of the damage inflicted on other spectrum users – such approaches may produce social efficiencies. To permit such innovative approaches to wireless communications would clearly be in the interests of consumers and businesses.

3. The use of "opportunistic" devises, however, is not accommodated within the FCC's traditional regime. While wireless users (including network operators) have long desired to use advanced systems to capture additional value in idle frequency space, they have been prevented from doing so by spectrum allocation rules. Loosening those restrictions, as has been done in some particular circumstances, has led to the use of devices that are far more agile in discovering and utilizing valuable bandwidth.

4. But, like the Interference Temperature NPRM, the Cognitive Radio NPRM fails analytically to evaluate the alternative policy approaches to spectrum sharing. In essence, it confuses the rhetoric of "flexible use" with public policy analysis. In licensed bands

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[1] Federal Communications Commission, *In the Matter of Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies, Authorization and Use of Software Defined Radios, Notice of Proposed Rulemaking and Order*, ET Docket No. 03-108 and ET Docket No. 00-47 (Terminated) (Released Dec. 30, 2003) ["NPRM"].

[2] Federal Communications Commission, *In the Matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands, Notice of Inquiry and Notice of Proposed Rulemaking*, ET Docket No. 03-237 (released Nov. 28, 2003) ["Interference Temperature NPRM"].

[3] Dr. Hazlett is a Senior Fellow at the Manhattan Institute for Policy Research, a columnist for the *Financial Times'* New Economy Policy Forum, and a former FCC Chief Economist. For more information, see: http://www.manhattan-institute.org/html/hazlett.htm. Dean Spitzer is Dean and Carl Mason Franklin Professor of Law, University of Southern California School of Law; and Visiting Associate, Division of Humanities and Social Sciences at the California Institute of Technology. For more information, see: http://www.usc.edu/assets/college/faculty/profiles/1925.html.

that are deregulated to the degree that the licensee has the opportunity to select technologies, outputs and business models, a description most appropriately attached to CMRS licenses,[4] extensive spectrum sharing has been enabled. Due to the incentives of licensees under liberal regulatory constraints, considerable investment has been undertaken to deploy innovative approaches. CDMA chips, used in wireless networks operated by Sprint PCS and Verizon Wireless, for instance, are classic examples of dynamic power control. These chips adjust 800 times per second to the minimum power level needed for successful communications. This frees spectrum for other services; the network operator gains by capturing part of the additional value generated for customers. As the technology is costly to create and deploy, operators weigh such outlays against the gains. This market process is widely seen – by economists and, in many previous statements, the FCC – as efficient.

5. Yet, in the Cognitive Radio NPRM, such market mechanisms are discussed only in passing. Instead, opportunities for innovation are discussed, almost entirely, in technical terms. The Commission desires to know how technologies work, what value they will bring,[5] and how they will interfere with other uses. Based on the answers it receives, it will then enact rules to enable the use of cognitive radios. This approach is command and control, despite the NPRM's frequent use of euphemism to describe the planning regime as "flexible" and "efficient."

6. A thorough critique of the NPRM is beyond the scope of this short Comment, but a key error is manifested in the NPRM's approach to "non-voluntary" transfers of spectrum use rights. The fundamental policy rests on the definition of "unused" or "under-utilized" spectrum, which is mischaracterized as a technical determination.[6] In fact, efficiency in spectrum use is an economic issue. A band that is intensely utilized by evidence of a spectrum analyzer may generate little service of value to consumers, and be ripe for reallocation. Conversely, a band which evidences little traffic may offer great value. It depends on the ability of entrepreneurs to use the bandwidth in question, and the willingness of users to pay for the resulting services. These are *economic outcomes* that are not accurately represented with *technical criteria*. In markets with flexible use rights, licensees make economic trade-offs between the value created, including those opportunities made possible with upgraded systems such as smart radios, and the cost of creating it. The efficiency of competitively determined decisions is well documented.

7. Interesting, the NPRM implicitly concedes this important distinction between economic and technical efficiency by deciding against "non-voluntary" unlicensed use of

[4] Evan Kwerel and John Williams describe commercial mobile radio services (CMRS) licenses as the most liberally defined spectrum use rights. Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002).

[5] The "value" of interest to the Commission is not that discovered by market competition, but that determined by an administrative process. See below.

[6] See, *e.g.*, Cognitive Radio NPRM, Par. 44.

certain restricted bands.[7] Here, the Commission deems the risk of interference too costly, even when the very same technical criteria used elsewhere identify bands as under-utilized. While the Commission believes it is appropriate for regulators to exercise such judgment concerning trade-offs, it is unwilling to permit consumers the same opportunity. The regulatory approach is to simply impose government rules. Alternatives allowing consumer preferences and entrepreneurial risk-taking to determine outcomes in a dynamic market process are excluded from consideration.

8. If the Commission wishes to over-rule markets, it should explain how market failure mitigates its own preference, expressed elsewhere, for market solutions. Undocumented dismissal of markets on the basis of, for example, "transaction costs," is insufficient. All processes entail transaction costs, including "non-voluntary" spectrum sharing. Under the appropriate cost-benefit analysis, transactional limitations associated with unlicensed spectrum use would not be ignored. Without exclusively-assigned rights, spectrum conservation – including agreements between rival users, technology standards, and technology upgrades – is limited to equipment design and use decisions (by manufacturers and FCC regulators). This eliminates market allocation decisions made by wireless licensees, who have instituted far-reaching efficiencies in organizing spectrum sharing involving literally tens of millions of users. They have also supplied productive innovations and, as the NPRM explicitly notes, have successfully deployed cognitive radio technologies. Hence, the case for "non-voluntary" spectrum rights transfers must show that *government sharing rules* increase the value consumers derive from the use of radio spectrum via alternative *market sharing rules*. That showing is not even attempted.

9. In its NPRM, the FCC conducts the wrong inquiry: "[W]e seek comment [sic] how cognitive radio capabilities might function together to achieve spectrum access, efficiency and interference mitigation."[8] First, the truth is that no one really knows how cognitive radios will work in the future. Second, we do know (from studying the history of such markets) that the best answers will be worked out via trial and error in the marketplace, given rules that permit rational allocation of spectrum by economically responsible parties. Third, by attempting to micro-manage cognitive radio, inserting itself into the technical details of alternative uses and business models, the FCC deters that market discovery process.

10. The superior approach is to consider how market incentives discover efficient solutions for cognitive radio (and other wireless applications). The limitations of the block allocation system, long studied by economists, should become the focus. Successful uses of advanced technologies should be investigated, not only with respect to technical innovations, but to the underlying economic incentives encouraging such innovations to flourish. That would provide rationality to a proceeding that now places the Commission in the position of choosing the appropriate spectrum sharing rules and then foisting them on the marketplace.

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[7] "We conclude that we should continue to prohibit unlicensed devices from emitting in designed restricted bands, which include many bands for Federal Government operations…" Cognitive Radio NPRM, Par. 31 (footnote omitted).

[8] NPRM, Par. 23.

ATTACHMENT

Thomas W. Hazlett and Matthew L. Spitzer,

Advanced Wireless Services, Spectrum Sharing, and the Economics of an "Interference Temperature"

April 5, 2004

Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
Establishment of an Interference Temperature	)	ET Docket No. 03-237
Metric to Quantify and Manage Interference	)	
and to Expand Available Unlicensed Operation	)	
in Certain Fixed, Mobile and Satellite	)	
Frequency Bands	)	

COMMENTS OF

THOMAS HAZLETT

AND

MATTHEW SPITZER

April 5, 2000

ADVANCED WIRELESS SERVICES, SPECTRUM SHARING,
AND THE ECONOMICS OF AN "INTERFERENCE TEMPERATURE"

Thomas W. Hazlett[1]

Matthew L. Spitzer[2]

April 5, 2004

A proposed "interference temperature," under which the FCC aims to identify "white space" in licensed bands to be made available for unlicensed underlays, is advanced to speed the introduction of advanced wireless services. Yet, the Commission fails to consider relevant policy alternatives, including a market-based model that extends exclusively-assigned flexible use rights. This omission is compounded by lack of any relevant economic analysis. Under-utilized spectrum space is identified in solely technical terms, ignoring both the magnitude of the costs imposed by the transfer of rights (which we show to be quite substantial) and the efficient use of "white space" in exclusively-assigned, flexible-use spectrum. Implementation of the proposal would impose certain wireless architectures at the expense of competing systems, an administrative mandate that denies consumers the opportunity to choose preferred alternatives, and which is likely to considerably lower the value yielded by incremental wireless services. This violation of "technological neutrality" is seen in the skewed nature of the proposal: while licensed overlays could be created in unlicensed bands under the Commission's "white noise" analysis, only the insertion of unlicensed underlays is considered.

This paper conducts the public policy and economic analyses omitted by the Commission, focusing on the use of CDMA systems in CMRS bands. The exclusive use model is shown to create highly efficient spectrum sharing rules; limiting this intense utilization of spectrum would produce very high social costs. Economic analysis focused on the proper margin leads to the strong conclusion that a regulatory transfer of spectrum access rights from licensed CMRS operators to unlicensed underlay rights would lead to a large decrease in social welfare. The paper offers alternative regulatory options for utilizing "white space," including assignment of exclusive overlay rights.

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I. INTRODUCTION

The Federal Communications Commission is considering implementation of an "interference temperature" ("INTEM"). The concept, which would allow new unlicensed devices to share spectrum "underlays" in licensed bands, is the subject of a rule making summarized in what we call the "INTEM Notice."[3] This FCC proposal develops a recommendation offered in the Spectrum Policy Task Force Report.[4] In this paper, we offer an analysis of the proposal at the request of Verizon Communications.[5]

The stated objective of the INTEM is to unleash social gains from productive use of radio spectrum, gains now blocked by traditional allocation mechanisms. The opportunity for more intensive use of radio spectrum is associated with the development of advanced wireless technologies that make it easier to pack additional communications into a given frequency space. The FCC believes that, prior to the emergence of such wireless systems as agile radios and "opportunistic devices," the traditional block allocation system worked well

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[3] Federal Communications Commission, *In the Matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands,* ET Docket No. 03-237 (Released November 28, 2003) ["INTEM Notice"].

[4] Federal Communications Commission, *Spectrum Policy Task Force Report*, *Report of the Interference Protection Working Group* (November 15, 2002), p.15.

[5] Either author has published voluminous research on regulatory policy and the economics of spectrum allocation. Relevant articles by Thomas W. Hazlett include, *The Rationality of U.S. Regulation of the Broadcast Spectrum*, 33 J. L. & ECON. (April 1990), 133-75; *The Cost of Rent Seeking: Evidence from the Cellular License Lotteries*, 53 SO. ECON. J. (January 1993), 425-35 (with Robt. J. Michaels); *Physical Scarcity, Rent Seeking, and the First Amendment*, 97 COLUM. L. J. (Novomber 1997), 905-944; *Assigning Property Rights to Radio Spectrum Users: Why Did FCC License Auctions Take 67 Years?* 41 J. L. & Econ. (October 1998), 529-575; *An Essay on Airwave Allocation Policy,* 14 HARV. J. L. & TECH. (Spring 2001), 335-566; *Property Rights and Wireless License Values*, AEI-Brookings Joint Center for Regulatory Studies, Working Paper No. 04-08 (March 2004). Dean Spitzer's research includes: *Controlling the Content of Print and Broadcast,* 58 SO. CAL. L. R. 1349 (1985); SEVEN DIRTY WORDS AND SIX OTHER STORIES: CONTROLLING THE CONTENT OF PRINT AND BROADCAST (Yale University Press, 1986); *Experimental Tests of the Coase Theorem with Large Bargaining Groups* (with E. Hoffman), 15 J. LEG. STUD. 149 (1986). *Coasian Solutions to the Externality Problem in Experimental Markets* (with others). 97 ECON. J. 388 (1987); *Justifying Minority Preferences in Broadcasting*, 64 SO CAL L R 293 (1991); *An Introduction to the Law and Economics of the V-Chip,* 15 CARDOZO ARTS AND ENT. L. J. 429 (1997); ADMINISTRATIVE LAW AND REGULATORY POLICY: PROBLEMS, TEXT, AND CASES, 5th ed. (with others) (Aspen, 2002); *Endowment Effects within Corporate Agency Relationships* (with Jennifer H. Arlen and Eric L. Talley), 31 J. LEG. STUD. 1 (2002); Joint research of the authors includes, PUBLIC POLICY TOWARD CABLE TELEVISION (MIT Press, 1997); and *Digital TV and the Quid Pro Quo*, 2 BUSINESS & POLITICS (August 2000), 115-59.

to separate one user from the next. The Commission sees the new science in wireless, however, as making the old regulatory structure obsolete, and calls for a series of new rules allowing unlicensed users to utilize spectrum in licensed bands.

This premise is correct in one basic respect: there is substantial under-utilization of radio spectrum. Many additional wireless services could efficiently be supplied to consumers, including those provided by innovative technologies. The social benefits of these services would – if provided in a cost-effective manner – exceed their social costs.

Yet the policy offered to pursue such gains is fundamentally flawed, and would not create mechanisms to produce valuable new communications without sacrificing service of much greater importance to consumers. The result of the policy's implementation, as outlined in the Notice, would be to substantially reduce social welfare. Indeed, many of the analytical errors in the INTEM framework are already embedded in current policies, where they demonstrably injure the economy by truncating the productive use of radio spectrum. Adoption of the contemplated rules will compound existing policy failures such that valuable new wireless technologies – which the Commission's new rules ostensibly seek to facilitate – will actually be suppressed. On the other hand, by extending policies proven to promote successful spectrum sharing among disparate users, the Commission could spur the creation of new efficiencies.

This paper is organized in the following manner. In Section II, we explain the FCC proposal for an Interference Temperature, which essentially transfers control over low power "underlays" from licensees to the government. The Commission sees this policy as mutually beneficial, allowing unlicensed users to access the underlays, while fixing interference boundaries to protect licensed services. We note major structural flaws in the FCC analysis, including the omission of either a public policy evaluation or an economic analysis considering costs and benefits of the proposed for reallocation, and the INTEM proposal's violation of technological neutrality. Section III then summarizes FCC spectrum allocation policy, focusing on exclusively-assigned, flexible-use spectrum, the regulatory model best applied to Commercial Mobile Radio Service (CMRS) licensees, and the allocation of unlicensed bands. This discussion includes an analysis of the relative social values of marginal allocations under alternative regulatory models.

Section IV charts the successful introduction of advanced wireless services, and the intense sharing of frequency space, under a liberal regime of exclusively-assigned spectrum access rights. Section V then evaluates the costs of increasing the noise floor in licensed bands as proposed in the Interference Temperature Notice, translating engineering data into economic losses. Simulations are reported for a generic CDMA carrier offering national service. The cost of increased interference is substantial. Using conservative assumptions, a single national network would incur additional outlays (both capital and operating costs) of an estimated $1 billion annually to maintain coverage and capacity (averaging across two mid-range scenarios, eliminating high and low projections). Expected gains from a new underlay allocation for unlicensed use, in contrast, appear relatively inconsequential. In Section VI we offer a policy alternative to the Interference Temperature, an expansion of exclusively-assigned overlay rights with relaxed regulatory requirements under the

Secondary Markets rules. We also recommend a Commission staff proposal that the FCC allocate unlicensed spectrum not by fiat but by auction bid. This market-based approach could form the basis of the experiment the Commission wishes to conduct. In Section VII we conclude with a summary of our analysis.

II. THE FCC'S "INTERFERENCE TEMPERATURE" PROPOSAL

We begin by describing the goal of the Interference Temperature proceeding. In Figure 1, adopted from the INTEM Notice, the radio space used by a licensee is graphically represented. The signal is strongest at the transmitter, and declines in strength as it travels. At some distance from the transmitter, it fades such that it is indistinguishable from various other emissions, which are characterized as the "noise floor." This electronic clutter is generated by various sources: nature (lightening, the warm earth itself), non-communications equipment emitting unintentional and incidental radiation (neon lights, a personal computer), spurious emissions, and out-of region wireless communications traffic.

Within a licensed band, signals are transmitted from an antenna[6] intended to reach receivers. When signal strength is only as strong as the noise floor, distinguishing the intended signal from other emissions is difficult. Traditionally, most wireless systems have been engineered such that coverage ends where signal strength equals that of the underlying noise floor. This is marked on the diagram as "Service Range at Original Noise Floor."

The Commission observes, however, that licensed radio services also seek to avoid signal degradation caused by interfering emissions above that caused by standard background noise. These often emanate from communications traffic, both in-band and out-of-band, causing spikes above the "noise floor" at certain times, places, and frequencies. Because they occur only intermittently, they do not eliminate reception of low power signals much, or even most, of the time. But because they can seriously degrade quality of service, licensed systems may be engineered to avoid this interference by relying solely upon higher power levels. This contracts geographical coverage, as shown in Figure 1 at the point marked, "Minimum Service Range with Interference Cap."

The essential proposition in the Interference Temperature put forth by the FCC is that there exists a well-defined space between the noise floor and the licensed signal floor, the minimum power used by the licensee in order to avoid intermittent noise jutting up above the noise floor. This space, defined in a given band in a given geographical market by the power of the signal at the receiver, is an area we label *Transfer*. The *Transfer* space carves out useful bandwidth from the licensed spectrum allocation, and reallocates it for use by unlicensed devices under FCC rules.

Unlicensed users are seen to be given valuable new opportunities. But the reallocation also appears to the Commission as agreeable to the licensed operator. First, the licensee is not seen to be productively utilizing the *Transfer* space, avoiding it in order to

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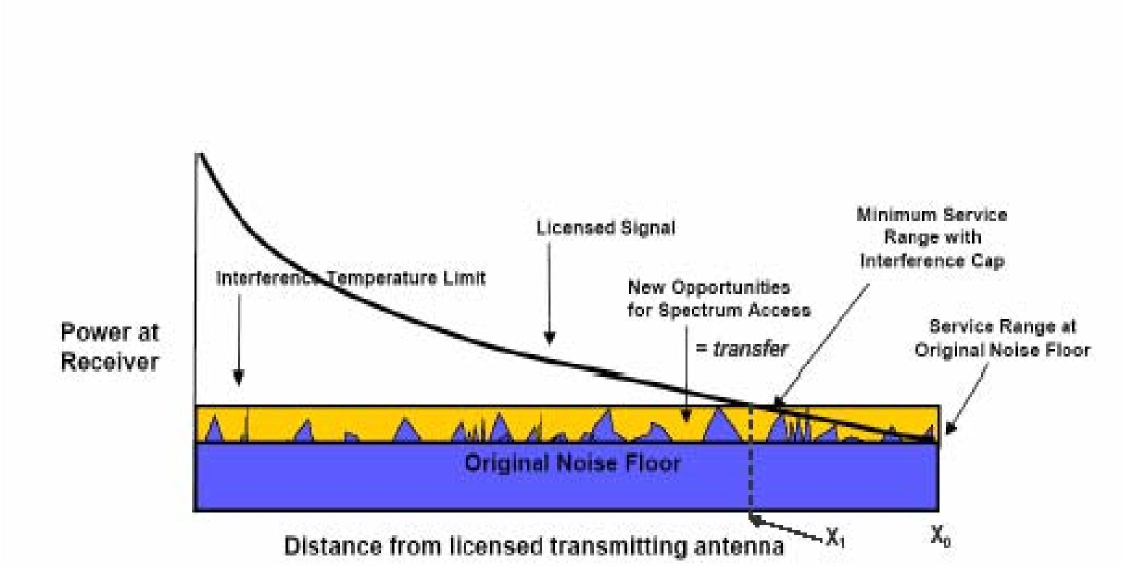
[6] The antenna can be installed almost anywhere, from a major tower to a chip in a handset.

escape intermittent interference. The FCC identifies this area "New Opportunities for Spectrum Access," on the grounds that it is not utilized by the incumbent licensee and, therefore, the opportunity cost of reallocation is zero. Second, the licensed operator is seen to gain security. By defining the *Transfer* space as bounded by the upper limit of the noise floor, the FCC sets an Interference Temperature. This boundary replaces the status quo, under which a rising level of encroachment may occur over time. Bandwidth available to the licensee is protected by an INTEM, reducing risk to infrastructure investments made by the licensee.

FIGURE 1. THE FCC'S BASIC PROPOSAL



Seen this way, imposition of an Interference Temperature produces mutually beneficial results. Licensed users gain protection from increases in the noise floor: "This would assure that the licensed operation would not experience any further degradation or loss of service from new interference, and thereby provide incumbents greater certainty… This could aid designers in balancing the numerous technical and economic tradeoffs involved in radio system planning."[7] While, on the other hand, new uses create value:

> This approach could also be beneficial for users of unlicensed devices. In areas where the interference temperature would not have been exceeded, opportunities would exist for additional operation by 'underlay' transmitters equipped to monitor the interference temperature and to control their operations so that they do not contribute to a condition where the interference temperature cap would be exceeded. Thus spectrum access for unlicensed users and devices would be increased.[8]

[7] INTEM Notice, par. 15.
[8] INTEM Notice, par. 16.

A. Public Policy Analysis

By focusing solely on how particular new low-powered systems – including agile radios, smart antennas, software defined radios, and other "opportunistic devices" – can share spectrum allocated to existing licensees, the Commission engages in a market engineering exercise. This skips an absolutely crucial step. The essential policy consideration is *how spectrum sharing rules should be developed* for wireless market participants. These rules can be imposed by government regulation, the choice implicitly made in the INTEM proceeding, which leaps the required policy analysis to directly move to planning how particular devices will share radio frequencies with certain other devices. Yet, an alternative mechanism for crafting sharing rules is available, and must be considered both because it has consistently performed extremely well in the marketplace and because it has been repeatedly endorsed by the FCC, based on this evidence, as an efficient structure for organizing airwave use.

FCC policy analyst Michael Marcus lays the theoretical foundation for the Interference Temperature proceeding, characterizing the proposed spectrum reform as driven by changing technology options.[9] Improved wireless technologies create new demands for spectrum access, while simultaneously creating much wider opportunities for sharing bandwidth. Marcus concludes that there is actually a reduction in spectrum scarcity, if new policy approaches like the Interference Temperature are implemented, due to the science now available:

> Today's spectrum managers are faced with a dilemma of growing spectrum demand coupled with low average utilization in large public sector blocks in urban area[s]. With traditional technology this dilemma was inevitable as public sector users need blocks of dedicated spectrum sized for peak demand. New technology can open new policy options for the spectrum manager here. We may no longer have to choose between 'guns and butter' but may be able to have the spectrum use associated with both at the same time through improve[d] policies and technology.[10]

While it is true that powerful new wireless technologies are being created, and that the creation of more valuable communications systems makes regulatory barriers ever more costly, the new options do not eliminate choices. Better ways to utilize spectrum *increase* the opportunity cost of deploying a particular technology to the exclusion of another. These costs do not disappear when government imposes mandates, selecting maximum power levels, permissible technical standards, or sharing protocols. This is reflected in the intense interest the FCC takes in defining how advanced wireless technologies work, how spectrum sharing is accommodated, how frequencies can be monitored. It seeks to make rules that will help some technologies, networks, services, or business models, at the expense of others.

Hence, there remain crucial policy choices. The most fundamental determine what process should be used to allocate spectrum for new wireless services. One approach is to

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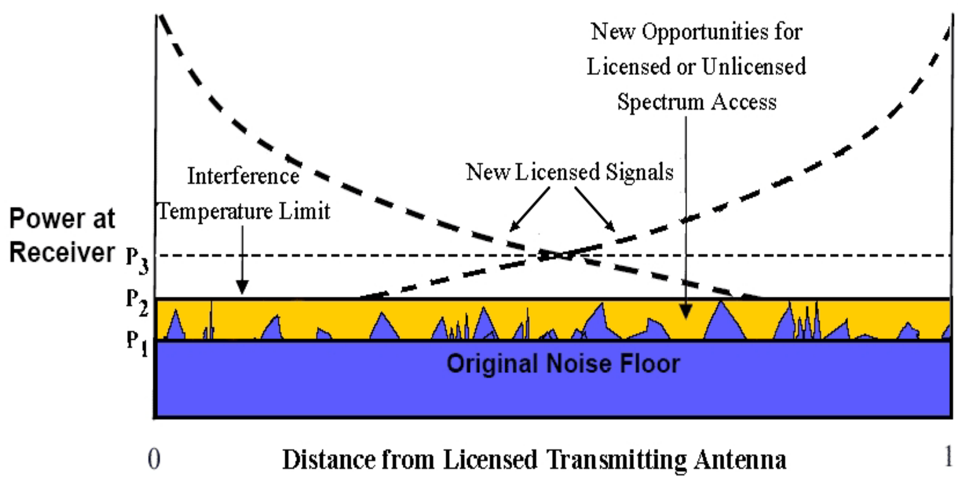
[9] M. J. Marcus, *Interruptible Spectrum: A Policy Prospectus*, Draft V (May 6, 2003).
[10] Ibid., p. 15.

mandate that bandwidth be used according to FCC power and protocol regulations. This is the approach proposed, *to the exclusion of any other candidate*, in the Interference Temperature Notice. An alternative approach, however, would respect the licensee's authority over the *Transfer* space, allowing market forces to determine how sharing arrangements are created, monitored, and adjusted over time, yielding incentives for the licensee to make efficient trade-offs. These productive sharing arrangements could be facilitated by allowing licensees to assign usage rights to third parties without the regulatory lags currently embedded in the Secondary Markets rules.[11]

Arguments favoring one or the other of these options center on economic incentives and transaction costs. We discuss these issues in some detail below, demonstrating that the existing evidence strongly suggests that granting licensees wide discretion to utilize spectrum capacity maximizes social value. Yet, before this debate can be concluded, it must first commence. The FCC Interference Temperature proposal must examine the alternative legal regimes under which its announced objectives can be met. The agency would then be in a position to present the possibility that inserting unlicensed users in licensed spectrum space via an FCC-monitored Interference Temperature delivers social value greater than wireless services delivered under an alternative approach, wherein market forces allocate spectrum to accommodate innovative technologies.

FIGURE 2. OVERLAYS ON UNLICENSED SPECTRUM



The importance of this policy analysis is seen in Figure 2, which shifts the focus of the discussion to an unlicensed band. Given power limits set by the FCC, suppose that the use of this unlicensed band was expanded by fixing an Interference Temperature at about the maximum power level recorded. After capping unlicensed device emissions at this level, suppose that the Commission licensed new operators to construct transmitters at much higher

11 Federal Communications Commission, *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, WT Docket No. 00-230, (Released October 6, 2003), pp. 17-20, Appendix B. We return to this point below.

power, say at Point 0 and Point 1. The newly authorized licensed services would utilize the entire band with power (at receivers) exceeding P_3.

This overlay policy differs, of course, from the underlay strategy proposed in the INTEM Notice, but each approach offers to produce new opportunities for advanced wireless services. How to compare their merit? In the Notice, the FCC simply assumes there is one option. In reality, there are many different ways the rules could be changed (in licensed or unlicensed bands) in an effort to squeeze more intense use of allocated bandwidth. In this paper we focus attention on the two most interesting approaches, unlicensed underlays (as offered by the Commission) and exclusively-assigned, flexible-use overlays.[12] We detail the margins on which these approaches can usefully be compared, and how the available evidence informs that comparison.

B. Economic Analysis

The INTEM Notice offers a technical analysis to answer an economic question. The resulting conclusion is confused. A spectrum analyzer graphic does not reliably separate "used" from "idle" bandwidth. Yet, Figure 1 leaps directly from a technical mapping of band emissions to a policy conclusion about the opportunity to insert unlicensed underlays to create "new opportunities for spectrum access." It would be exactly parallel to the analysis presented in Figure 2, except for the fact that we do not commit the FCC's error in presenting a technical diagram to substitute for economic analysis.[13]

What matters to consumers, business, and government users are costs and benefits of alternatives. If, for instance, the area identified as *Transfer* in Figure 1 benefits unlicensed users by $100, but eliminates voice and data services for licensed customers worth $10,000, then the FCC's spectrum usage diagram – which portrays the area as vacant space – is irrelevant. Moreover, engineering experts familiar with system operations may consider it dead wrong. That is because what looks "quiet" or "noisy" depends critically on network architecture, and can change dramatically over time. As applied to licensed CDMA networks, for instance, the *Transfer* space is highly productive.[14]

[12] We apply this regulatory model not to overlays of unlicensed bands, as hypothetically considered just above, but to licensed bands.

[13] The logic of Figure 2 is symmetric to that in Figure 1; hence, we do not utilize it in our analysis. Its purpose is to point out the asymmetry of the Interference Temperature Notice's policy conclusion.

[14] Reply Comments of V-Comm L.L.C., *In the Matter of Commission Seeks Reply Comments on Spectrum Policy Task Force Report*, ET Docket No. 02-135 (February 28, 2003), p. 19, Jackson 2004, Declaration of Dr. Charles L. Jackson regarding Limits to the Interference Temeprature Concept, *In the Matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands,* ET Docket No. 03-237 (April 5, 2004) ["Jackson 2004"], Federal Communications Commission, Comments of Lucent Technologies, Inc., *In the Matter of Commission Seeks Public*

But the error committed by the FCC proposal is even more fundamental. Even if some technical experts concluded that the *Transfer* area was not utilized by licensed systems, the public policy argument for reassigning those rights to unlicensed underlays would not be addressed. That argument requires evidence that the economic benefits created by a shift in rights will yield benefits in excess of their costs.[15] Given that the licensee is very well positioned to consider the competitive benefits of efficiently utilizing the opportunity afforded by the *Transfer* space, removing this rational allocation process should meet a high burden. A compelling case that market failure exists, and can be remedied by regulatory determination of new spectrum use patterns, is required.[16] That analysis is not drafted, let alone completed, in the INTEM Notice.

In fact, increased noise levels in licensed bands may inflict large economic costs. Again we focus on the commercial mobile radio service (CMRS) bands. The first source of economic damage comes from the reduction in coverage that the INTEM imposes. In Figure 1, signal distance is demonstrably reduced from X_0 to X_1. There is no a priori reason to suspect that this reduction has a de minimus impact on network quality or, conversely, costs. To the contrary, available evidence suggests that the coverage reductions would inflict substantial economic damage on networks and, therefore, their customers. Radio engineering expert Charles Jackson identifies this as about a 17% additional capacity reduction in the hypothetical situation presented in Figure 1 of the INTEM Notice.[17]

As explained in greater detail by Jackson, there is a standard trade off between noise temperature and communications volume. It is formally given by Shannon's Law. For a single 30-MHz wide point-to-point channel (analogous to broadband PCS licenses) capacity losses are substantial. Table 1 shows percentage capacity losses at varying power and noise levels. (Later, we will attempt to translate such losses into economic costs, focusing on CDMA systems.) Dr. Jackson notes that "a noise temperature of 300 K is approximately the lower limit on PCS system noise and is set by nature."[18] Capacity reductions are measured relative to this base level in bits/second. Losses vary with power; levels in the table are similar to those in PCS networks.

Comment on Spectrum Policy Task Force Report, ET Docket No. 02-135 (February 28, 2003).

15 The general analysis of how to efficiently assign rights is presented in Harold Demsetz, *When Does the Rule of Liability Matter?* 1 J LEG STUD 13 (1972).

16 That burden includes compelling evidence that the proposed transfer improves the status quo *and* is superior to alternative reforms. This engages the issue of expanding flexibility of exclusively-assigned rights, discussed below.

17 "That is, the remedy for interference blocking service in 3% of the original service region is to declare defeat and give up on an additional 17% of the service region." Declaration of Dr. Charles L. Jackson regarding Limits to the Interference Temeprature Concept, *In the Matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands,* ET Docket No. 03-237 (April 5, 2004) ["Jackson 2004"], p. 6.

18 Jackson 2004, p. 23.

Theoretical losses for plausible power and noise values are substantial. Annual revenues for wireless telephone service (voice and data) in the United States totaled about $88 billion in 2003. To the extent that new unlicensed underlays increase noise levels, economic costs would be incurred.[19] Take the lowest levels of capacity loss, occurring for received power levels of -70 dBm (powers that are impracticably high for cellular/PCS). If an INTEM proposal produced an increase in noise in the cellular/PCS bands of 300 K to 600 K, within the realm of increases contemplated by the analysis in the Notice and in the Spectrum Policy Task Force Report, capacity reductions translate into very large economic costs. Just a ten percent decline in communications capacity, as would occur (assuming a system operating at a received signal level of -70 dBm), implies social losses of billions of dollars annually for plausible estimates of consumer and producer surplus.

TABLE 1. LOSS OF SHANNON CAPACITY OF A 30-MHZ CHANNEL AS A FUNCTION OF NOISE (OR INTERFERENCE) TEMPERATURE (LOSS RELATIVE TO CAPACITY AT 300K)

		Received Power (dBm)				
		-110	-100	-90	-80	-70
Noise Temperature (K)	300	0%	0%	0%	0%	0%
	600	49%	43%	27%	15%	10%
	900	66%	60%	41%	24%	16%
	1,200	74%	69%	50%	31%	21%

Source: Jackson 2004, p. 24.

Wireless carriers would react to this loss of capacity by considering various means of acquiring additional capacity, potentially lessening economic loss. Gaining access to greater bandwidth, or using existing networks more intensely, would be options. The latter could include building a larger number of cell sites (and base stations) and/or upgrading technology. Importantly, if the licensed operator controls the *Transfer* space, an important, additional set of options is available: regulating access to maximize value. The gains associated with each option are complex, encompassing revenues from users, advertisers, device makers, application suppliers, or others, depending on the business model(s) adopted.

In sum, operating new unlicensed devices in a band raises the average noise floor even if those devices are smart enough to avoid raising the worst-case noise floor, and raising the average noise floor imposes non-trivial costs. Licensed operators seek to minimize those costs, but under the Interference Temperature policy could not consider controlling what is

[19] Even if actual usage of underlays turns out to be light, they will be costly if licensed systems are engineered to use higher power levels.

the cause of the new costs; these uses would be regulated by the FCC which decides how use is made of the "underlay." The structure of rights chosen for the underlays, open access regulated by FCC rules, makes negotiation with unlicensed users impossible; no agent speaks for all potential users. The result is that decisions about use of the *Transfer* area are removed from the economic rationality of competitive markets, and imposed by government edict. Costs may be incurred that are far higher than the benefits created. The insertion of unlicensed underlays by regulators displaces cost-benefit calculations performed by profit-maximizing operators.

By characterizing the Interference Temperature rule making as a technical definition problem, as is done in the INTEM Notice, high social costs are already visible. Licensed users can and do make highly valuable use of the space the Interference Temperature analysis identifies as empty. Take CDMA technology, deployed nationally in the networks of both Sprint PCS and Verizon Wireless, and carefully calibrated to use the minimum level of power necessary to transfer a given increment of information. Power is adjusted dynamically, using extremely advanced wireless technology. A CDMA chip changes its power usage *hundreds of times per second*,[20] searching to discover the minimum power consumption needed to make a connection. As described by an industry analyst:

> What makes the CDMA uplink channel unique is that the per-data bit transmit power of each mobile unit is constantly and precisely controlled so that the signals arriving at the serving base station are at about the same level. What's more, the mobile transmit power is always controlled so that the received signal is just sufficient to allow reception without any frame errors. You might think that in a heavily loaded channel the combined signals from many mobiles would be well above the noise floor, and thus a modest change in the thermal noise level would have no effect. This is not the case, however. In fact, in a properly operating uplink CDMA channel, the noise floor precisely defines the required receive signal even at maximum channel loading. This can be demonstrated on a heavily loaded CDMA channel by momentarily and artificially increasing the noise figure of base station receivers. Increase noise figure by 3 dB (the functional equivalent of a 3 dB noise floor rise) and the average transmit power of each served mobile will immediately increase by a similar amount.[21]

In addition to extending battery life, the use of reduced power preserves spectrum capacity for other users. Carriers effectively create bandwidth by deploying power-saving technologies, productively utilizing "underlays" of maximum power licensed signals. Hence, Figure 1 identification of the Transfer space as currently unused is hugely misleading. Three aspects of the economics are crucial to the policy discussion.

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[20] "... CDMA handsets adjust their power output 800 times per second in response to signals from nearby base-stations." *Spread Betting*, THE ECONOMIST (June 19, 2003), http://www.economist.com/science/tq/ PrinterFriendly.cfm?Story_ID=1841059.

[21] Elliott Drucker, *Time to Take 'Noise Temperature' at FCC,* WIRELESS WEEK (March 22, 2004).

- Exclusively-assigned, flexible-use spectrum rights create powerful incentives for licensees to invest in bandwidth conservation. Network operators internalize gains from sharing spectrum more efficiently, by realizing access fees (e.g., subscription and per-minute charges) while simultaneously absorbing costs. Hence, each margin on which spectrum capacity can be increased is evaluated in a socially optimal context. Innovations expected to produce consumer benefits exceeding their costs are adopted; projects flunking the market test are rejected.

- This cost-benefit calculus extends broadly. Investments in basic research and development, technology upgrades, and network extensions are efficiently undertaken. Hence, when a new opportunity to reduce power without sacrificing quality becomes available, the cost of deploying the innovation is weighed against the value of the gains created – including increased battery life and additional communications traffic.

- Identifying "low power" areas available for increased utilization is an economic, not a technical, exercise. To reallocate such areas from licensed to unlicensed use may impose substantial costs on consumers. This may be true even where spectrum space does not appear to be currently deployed, if it undercuts incentives to dynamically expand frequency use over time. By denying the efficient user of the underlay – the band licensee – the opportunity to expand productive use of this space, social value is sacrificed.

C. Technological Neutrality

A crucial policy consideration arises from the economic discussion. There is no more widely accepted principle of economic regulation than the standard of "technological neutrality." When government departs from neutrality, it engages in industrial policy that supplants technologies offered by market competition – with its rich sources of information gleaned from decentralized decision making, profit incentives, feed back loops, and continuous testing for efficiencies. Administratively determined market structures have not fared well in comparison to competitive markets, as learned in countless real-world experiments, not the least of which involve wireless communications markets. The FCC has itself noted that the development of wireless telephone networks is a perfect demonstration of the superiority of market competition in assembling resources – including radio spectrum – to produce valuable service to the public.[22]

That logic is abandoned in the INTEM Notice. Having identified what it perceives to be under-utilized radio space, the Commission suggests a reallocation from licensed to unlicensed use. This imposes a government plan to select "winners" (unlicensed devices

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[22] Federal Communications Commission, *Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services, First Report,* FCC 95-317 (released August 18, 1995), par. 4.

fitting FCC rules) and "losers" (licensed operators). The most serious losses will be inflicted on licensees that have deployed the most advanced techniques for utilizing the low power frequency space (such as CDMA systems) now reassigned for other uses. Even proponents of unlicensed spectrum allocations concede that certain technologies are hurt, relative to others, when underlays are created. As a group of advocates for additional unlicensed allocations recently told the Commission in a proceeding involving the MMDS band,

> To be fair, ITFS/MDS licensees are correct that to the extent that they use their spectrum in very low power situations, a low-power unlicensed underlay creates a more serious interference problem.[23]

This logic is correct, and it establishes the technological non-neutrality of the policy of indiscriminant underlay insertion. Systems which productively use the underlay space will be harmed relative to those systems that do not. But neutrality is not, it seems apparent, restored by discriminating between technologies. First, what the Commission deems to be productive use of licensed spectrum space is likely to differ from what market competitors, subject to cost and revenue incentives, see as productive. Second, should the Commission attempt to reverse the asymmetric outcome above, such that systems that appear to the FCC to be productively using "very low power situations" will not be forced to share licensed frequency space with unlicensed underlays, the asymmetry does not disappear but reverses. Networks that elect different systems will be treated differently. This approach would bias carrier technology decisions, rewarding some systems with valuable options denied others.

The INTEM proposal fundamentally alters the economics of alternative technologies and business models; the Commission chooses, implicitly or explicitly, those it prefers. By imposing tight power limits for individual users, and by providing for unlimited (unpriced) access for approved devices, it favors some wireless services, and business models, and effectively rules out others. FCC rules, not consumers in the marketplace, determine that Intel's Centrino chips are preferred over Qualcomm's CDMA chips, that the local area networks provided by WiFi access points are socially more useful than a wide area data network provided by a GSM EDGE,[24] CDMA EV-DO,[25] Flarion OFDM,[26] IPWireless TD-CDMA,[27] or another system optimized for licensed radio spectrum.[28]

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[23] Federal Communications Commission, *In the Matter of Amendment of Pars 1, 21, 73, 74 and 101 of the Commission's Rules to Facilitate the Provision of Fixed and Mobile Broadband Access, Educational and Other Advanced Services in the 2150-2162 and 2500-2690 Bands*, Reply Comments of New America Foundation, et al., WT Docket No. 03-66, RM-10586 (October 23, 2003), p. 15.

[24] EDGE technology upgrades GSM wireless networks, such as the one deployed nationally by AT&T Wireless, to deliver 144 kbps access to the Internet. AT&T Wireless, *AT&T Wireless Takes its Customers to the EDGE* (November 18, 2003), http://www.attwireless.com/press/releases/2003_releases/111803.jhtml.

[25] EV-DO technology overlays a 1X CDMA network to provide 2.3 mbps wireless access. It has been deployed by Verizon Wireless in Washington, D.C. and San Diego, and the company has announced that it will be available nationwide by year-end 2004. USA TODAY.COM, *Verizon hooks up Wi-Fi alternative; Broadband Access zippier than its*

The optimal policy regime would encourage competition between rival technologies in the marketplace. This occurs when rules are crafted such that investors are free to build networks offering service, and consumers are free to choose among the alternatives. The price system can be used to ration spectrum access, and a rational trial and error process will discover efficient outcomes. Allowing flexible use of licensed spectrum controlled by numerous rivals provides just such an opportunity for social welfare maximization. In fact, such licenses ought to be made more flexible, allowing licensees to assign control over spectrum use to third parties without FCC notification or transfer approval. This extension of the Secondary Market rules[29] would enable a licensee to delegate spectrum control to device owners, and to negotiate the price of access with device makers. Private firms, organizations, universities, user groups, or industrial contortia, then, would be able to establish their own rules for unlicensed use. Firms that argue for unlicensed spectrum to be allocated by the Commission, such as Intel,[30] Microsoft,[31] Apple,[32] or Cisco,[33] would be allowed to bid for licenses conveying rights to establish the use and technology standards they advocate. This

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predecessor (March 25, 2004), p. B03. Sprint PCS deploys 1X nationwide, which delivers 144 kbps wireless access, and plans to deploy EV-DV, delivering speeds faster than 3 mbps, in the future. *Defining 2.5G and 3G Networks: has Wi-Fi stolen the 3G show?* WIRELESS BUSINESS & TECHNOLOGY (December 1, 2003), p. 44.

[26] Current Analysis, *Flarion Paves a 4G Path for Nextel with FLASHy OFDM Trial*, COMPETITIVE INTELLIGENCE REPORT (February 12, 2004).

[27] Timothy Sanders, *Bullish on the Band: Vendors Sound Off on Broadband Wireless for 2.5 GHz Spectrum,* 4 BROADBAND WIRELESS ONLINE (September/October 2003), http://www.broadband-wireless.com.

[28] This set of technologies appears to include WiMax, by many accounts the most advanced technology thus far emerging from the "WiFi" family. THE HARTFORD COURANT, *Wi-Fi? How About Way Far? WiMax Delivers High-Speed Wireless Internet Service as Far as 35 Miles Away* (March 25, 2004), p. D3. See discussion below.

[29] Federal Communications Commission, *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, WT Docket No. 00-230 (Released October 6, 2003), pp. 17-20, Appendix B.

[30] Pitsch, *The Future of Radio Spectrum Policy*, TECHNOLOGY@INTEL MAGAZINE, http://www.intel.com/update/contents/st02041.htm

[31] Comments of Microsoft Corporation, *In the Matter of Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 03-122 (September 3, 2003), pp. 2-3.

[32] Comments of Wireless Information Networks Forum, *Apple Computer, Inc. Petition for Rulemaking to Allocate Spectrum in the 5 GHz Band to Establish a Wireless Component of the National Information Infrastructure*, RM-8653 (July 10, 1995).

[33] Cisco Systems, *Wireless and Spectrum Management*, http://www.cisco.gov/networks/wireless_spectrum_management.html

would allow consumers to select a competitive solution rather than facing just the one imposed through government mandate.[34]

Without marketplace feedback, how is government to judge the merit of a "low power" unlicensed solution versus any one of a number of "high power" licensed solutions? The answer to this question is informed by contrasting the underlay options favored in the INTEM Notice with rival technologies emerging in exclusively-assigned, flexible-use spectrum. For instance, in Australia, where liberal spectrum policies have permitted investors to create "4G" wireless networks, this assessment was recently offered:

> Personal Broadband Australia's iBurst network is a connectivity cure-all for everyone from road warriors to home users. The former will appreciate the ability to connect from almost anywhere without hunting down Wi-Fi hotspots or facing outlandish GRPS data rates. But iBurst isn't just for the mobile set: the service brings broadband within reach of homes not serviced by ADSL and cable.
>
> Due for launch in December, iBurst makes clever use of portions of the 3G mobile phone spectrum to provide users with always-on Net access with a reach and data rate that puts Wi-Fi to shame...[35]

It remains to be seen how widely this view is shared by consumers in the market. What is evident, however, is that some systems optimized for network-coordinated spectrum use may meet user needs more efficiently than other systems optimized for decentralized spectrum access. Spectrum allocation decisions imposed by regulators overrule consumers' choices. Technological neutrality is violated, and government planners effectively select winners and losers.

III. FCC SPECTRUM REGULATION OPTIONS

The FCC relies on a tripartite view of regulatory choices, in which licensed "exclusive use," an unlicensed "commons," and "command-and-control" form three rival modes.[36] This taxonomy can actually confuse the regulatory choices, however. First, licensed use has typically been highly regulated, with the result that market outcomes have reflected both the profit incentives of private licensees and the spectrum management policies imposed by regulators. Second, "exclusive use" is not an apt characterization for liberally defined wireless licenses, which host intense sharing of allocated spectrum. Third,

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[34] Prof. Benjamin notes that particular protocols or standards imposed via unlicensed rules themselves bias technology outcomes. Stuart Benjamin, *Spectrum Abundance and the Choice Between Private and Public Control*, 78 NYU L R 2007 (Dec. 2003), pp. 2046-7.

[35] Dan Warne, *Bursting Through*, AUSTRALIAN PERSONAL COMPUTER (November 17, 2003), http://www.apcmag.com/apc/v3.nsf/0/EABDFD174F749AF4CA256DE0007CD3AD.

[36] Federal Communications Commission, *Spectrum Policy Task Force Report* (November 2002), p. 5.

important aspects of unlicensed use are subject to command-and-control, with rules applied to wireless equipment rather than users. Power limits and other constraints are applied in the certification process, and these are designed to help keep uncoordinated users from interfering with each other. Both unlicensed bands and heavily regulated licensed bands rely on control mechanisms provided by regulators.[37] Indeed, because the bandwidth underlying any allocation is allocated administratively, top-down commands are generally involved across all regulatory categories.

This has not proven successful, and a "consensus is forming that the current process of allocating radio spectrum by administrative decision-making is in serious need of reform."[38] The observed failure of central planning to deploy spectrum to do the most good is only half of the story, however. The other half is the observed success of deregulation in licensed and unlicensed bands, where greater reliance on market forces has been facilitated by regulatory reform. The reasons driving successful applications are quite similar, even as the applications (as well as the policies) appear to be quite distinct. We call one regulatory model "exclusively-assigned, flexible-use spectrum" (EAFUS), and it is best represented in the U.S. market by the regime governing the approximately 189 MHz allocated to CMRS licenses. It is crucial to distinguish this relatively parsimonious allocation with the much broader allocations to heavily regulated licenses, including those for the TV band[39] or MMDS.[40] The unlicensed regime encompasses several bands, all of which restrict communications to low power devices which are most easily deployed for short-range services, such as remote controls and home WiFi systems. See Table 1 for a brief summary. We discuss these approaches in order.

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[37] FCC economist Douglas Webbink wrote in 1987: "Both common property and inalienable rights weaken the incentive to use efficiently and to conserve resources compared to private property rights, since users cannot capture all the benefits of conserving, using efficiently, and improving the use of such resources." Douglas W. Webbink, *Radio Licenses and Frequency Spectrum Use Property Rights*, 9 COMM & L 3 (June 1987).

[38] Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 1.

[39] Thomas W. Hazlett, *The U.S. Transition to Digital Television: Time to Toss the Negroponte Switch*, AEI-Brookings Joint Center for Regulatory Studies Working Paper 01-15 (November 2001).

[40] "The 2.5 GHz [MMDS] band has labored for years under the heavy hand of command-and-control regulation. The regime has not served the American people or the Commission's licensees particularly well. Our rules have, at times, been complex and stifling, and have shifted in their objectives . . ." *NPRM*, 18 FCC Rcd at 6858 (Separate Statement of Chairman Michael K. Powell).

TABLE 1. FLEXIBLE-USE LICENSED AND UNLICENSED BANDS (MONETARY VALUES FOR 2003)						
Band	MHz	Type	Services[1]	Service Rev.	Equip. Rev.	Network Capex
1.9 GHz	20	UNL	Voice, data, UPCS (Unlicensed PCS) handsets	~ 0[2]	~ 0[2]	~ 0[2]
900 MHz, 2.4 GHz	26 83.5	UNL	Remotes, listening devices, cordless phones, wireless LANs, WiFi, microwave ovens, ISM equipment, local positioning systems, experimental use by schools	$0.03 billion[3]	$3.81 billion[4]	$0.5 billion[5]
5 GHz	555 MHz	UNL	WiFi, HiperLAN, HiSWAN, IEEE 802.16 devices, cordless phones, amateur radio, field disturbance sensors (such as door openers), aviation radar	~ 0	$0.16 billion[6]	$0.02 billion[7]
800 MHz, 1.9 GHz	189 MHz	LIC	Mobile phones, data	$88 billion[8]	$13 billion[9]	$21 billion[10]

Notes and Sources: See Appendix A.

A. Exclusively-assigned, Flexible-use Spectrum (EAFUS)

The productivity of exclusively assigned, flexible use spectrum has been so pronounced that the policy "solution, according to most economists, is to replace the current administrative allocation with a spectrum market."[41] Reform has produced new efficiencies by liberalizing the rights granted licensees,[42] permitting profit-maximizing firms, constrained by competitive forces, to determine how spectrum is used. The EAFUS licensee tends to discover and deploy efficient wireless solutions, as it internalizes both the expense and the gains from creating valuable services. This makes the licensee a zealous protector of radio

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41 Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 1 (footnote omitted). The success of the "property rights" model in producing efficiencies relative to alternative regulatory models is discussed extensively in Hazlett, *An Essay on Airwave Allocation Policy*, op cit.

42 Some countries have gone much further in deregulating exclusive assignments than the U.S. See Thomas W. Hazlett, *Property Rights and Wireless License Values*, AEI-Brookings Joint Center for Regulatory Studies Working Paper No. 04-08 (March 2004), http://www.aei-brookings.org/publications/abstract.php?pid=631.

space, an aggressive investor in infrastructure, and a risk-taking entrepreneur in search of new 'killer apps.' In the relatively limited EAFUS allocations in the U.S., enormous social value has been created. Given annual service revenues of about $88 billion, and assuming that consumer surplus equals about one-half of total revenues, consumer gains (ignoring profits) of about $44 billion per year are produced.[43] The impressive gains are achieved due to intense utilization of less than 189 MHz[44] spectrum shared by over 150 million subscribers.

In a recent FCC working paper, economist Evan Kwerel and engineer John Williams consider how additional competition and advanced wireless technologies could be accommodated in the relatively crowded, but relatively user-friendly, frequencies below 3 GHz.[45] The paper offers two public policy insights directly relevant to the INTEM Notice. The first is that shared used of a band does not require an unlicensed regulatory model:

> Future expansion of dedicated spectrum for unlicensed use could be obtained through negotiation between the manufacturers of such devices and spectrum licensees. One possible arrangement would be for a licensee or group of licensees covering a particular band throughout the U.S. to charge manufacturers a fee for the right to produce and market devices to operate in that band. Such contracts could provide different grades of access for different fees, thus providing for a wider range of uses than are possible under the current rules. Competition between licensees would ensure that fees reflect the opportunity cost of the spectrum. Alternatively, manufacturers of low power devices might form a bidding consortium to acquire additional spectrum…[46]

In fact, the suggestion that "exclusive use" spectrum can efficiently serve multiple users, applications, or networks is scalable. When regulated liberally, such that licensees have the right to broadly determine spectrum use within the allocated frequency space, the EAFUS model has proven extremely effective at creating sharing opportunities, at inventing and deploying compatible technologies, and at maintaining and upgrading wireless infrastructure to accommodate a broad range of diverse, valuable uses. Further liberalization of licensees would assist this process of discovery by encouraging "creative destruction," the evolution of superior economic structures through competitive trial and error.

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43 This first approximation employs the rule of thumb that consumer surplus is approximately one-half total revenues. This relationship is holds precisely when the elasticity of demand at the market equilibrium = -1 and the demand function is linear.
44 http://wireless.fcc.gov/services.
45 Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002).
46 Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 31.

Specifically, relaxed Secondary Markets rules could permit licensees to reassign control over spectrum without receiving FCC approval (which can now take up to twenty-one days, even if routinely processed[47]). By restricting regulation to the licensee's liability for out-of-band emissions, the licensee could supply 'open access' for purchasers of approved devices. While various options are possible, the most evident business model anticipates the EAFUS licensee negotiating long term contracts with device manufacturers. Individual users then purchase spectrum access bundled with their wireless equipment. A market supplied 'commons' results. This is similar, in many respects, to the structure of CMRS service markets today. Customers purchase mobile phones, personal digital assistants, or data network PCMCIA cards as plug 'n play devices that automatically access licensed spectrum according to protocols established by wireless licensees.

The second important insight brought forth by Kwerel & Williams in this context deals with the reverse situation. When spectrum use rights are issued non-exclusively, coordination problems can easily arise. These make optimal use of bandwidth more difficult, and often require regulatory solutions:

> In shared bands, just providing technical and service flexibility would not create the correct incentives for economically efficient use of the spectrum, because licensees can not capture the benefits from deploying spectrum-conserving technology.[48]

When there is no economic entity that takes into account the gains and losses from efficient airwave use, inefficient outcomes are likely. This is true both in the initial allocation stage, when the value of a band in unlicensed use is being compared to the value of the band under an alternative designation (say, EAFUS), and when new demands or technologies render existing non-exclusive uses obsolete:

> Restructuring unlicensed bands solely through the use of an auction does not appear feasible. Since users of unlicensed bands have no exclusive rights and there is generally no record of the current incumbents (users) to whom such rights might be assigned, participation in an auction would not seem feasible. Any restructuring of unlicensed bands will probably require an administrative solution.[49]

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[47] Federal Communications Commission, *In the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, WT Docket No. 00-230, FCC 03-113 (released October 6, 2003), p. 7.

[48] Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 5.

[49] Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 30.

Without a responsible party internalizing costs and benefits, there is no accurate way to measure value.[50] This leads Kwerel & Williams to suggest that bands set aside for unlicensed use at least be procured by a bid tendered by the government in an open auction process: "If there is a continued desire as a matter of public policy to provide spectrum for such devices on a 'free' basis, the FCC itself might purchase the spectrum in the auction… This would have the advantage of making the opportunity cost of such allocations more explicit."[51]

In sum, the analysis reveals that:

- Licensed bands are used by advanced wireless devices that are extremely adept at dynamic frequency sharing;
- Agile technologies are utilized extensively under the subscriber model, and could be utilized under an 'open access' model given FCC reforms to enable more far-reaching secondary market transfers;
- Eliminating exclusivity increases potential coordination problems, undermining incentives to conserve bandwidth;
- Eliminating exclusivity rules out market pricing, leaving policy makers without the data necessary to compare the value of alternative spectrum allocations.

B. Unlicensed Spectrum

Unlicensed bands now host many popular services that have created considerable social value. Since rules for unlicensed use were expanded to accommodate newer technologies and a broader class of services in the 1980s, a great deal of new wireless activity has occurred in the bands primarily affected, 900 MHz and 2.4 GHz.[52] The policy implications have generated considerable confusion, however. This is seen in the manner in which unlicensed use is declared to (a) be successful, and (b) justify greater spectrum

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[50] The problem created when there is no market feedback establishing relative values for alternative uses of radio spectrum has long been seen, and has not been solved. Douglas Webbink, writing in 1977, began his analysis by noting: "Because the spectrum is a scarce, non-priced resource whose ownership rights are freely transferable, the use of the spectrum is inefficient." Douglas W. Webbink, *The Value of the Frequency Spectrum Allocated to Specific Uses*, 19 IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY (August 1977), p. 343.

[51] Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 31.

[52] The key reforms were permission to use spread spectrum technologies in 1985, and, in 1989, the standardization of service categories for equipment seeking FCC approval under Part 15 rules. See Kenneth R. Carter, Ahmed Lahuoji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, OSP Working Paper Series No. 39 (May 2003), pp. 7-8.

allocations for unlicensed use. A pronouncement featured in a parallel rule making provides a clear example of the analysis:

> The Commission's rules for unlicensed transmitters have been a tremendous success. A wide variety of devices have been developed and introduced under these rules for consumer and business use, including cordless telephones, home security systems, electronic toys, anti-pilfering and inventory control systems and computer local area networks. Moreover, the past few years have witnessed the development of industry standards, such as IEEE 802.11b (Wi-fi), Bluetooth, and Home RF that have greatly expanded the number and variety of devices that operate in the 2.4 GHz ISM band.[53] This has provided for the introduction of wireless headsets and computer connections for cellular and PCS phones, wireless computer peripherals such as printers and keyboards, and a host of new wireless Internet appliances that will use all of the spread spectrum bands. Because of this, a large number of new devices have been developed and placed into operation in the ISM bands.
>
> The success of our unlicensed device rules for the ISM bands shows that there could be significant benefits to the economy, businesses and the general public in making additional spectrum available for unlicensed transmitters.[54]

There are two fundamental flaws in this logic. The first is that the "tremendous success" is identified without regard to the opportunity cost of spectrum. This approach assumes there are no alternative uses foreclosed by unlicensed allocations, which is untrue. As relates to the 900 MHz and 2.4 GHz bands, however, it is certainly plausible that the alternative uses for the bands *likely to be allowed under FCC regulation* were not so valuable as the unlicensed services actually allowed. One key driver of unlicensed band use has been the pent-up demand for spectrum access. Because Commission policies have so effectively prevented productive utilization of bandwidth, protecting old technologies allocated wide bandwidth with little resulting output (as measured by consumer demand), the use of some unlicensed frequencies has been relatively intense. The demand for short-range wireless devices (or services) has been supplied, largely due to regulatory constraints, with few competing options.

But even if these bands have been productive relative to alternative uses of the allocated spectrum, this does not imply that additional spectrum would produce the same efficiencies. The trade-off between unlicensed and its alternatives must be evaluated at the

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53 These operating standards provide manufacturers with guidance for developing spread spectrum devices for the 2.4 GHz band. The IEEE 802.11b standard applies to direct sequence devices, while the Bluetooth and Home RF standards apply to frequency hopping devices. (Footnote from quotation.)

54 Federal Communications Commission, *In the Matter of Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band*, ET Docket No. 02-380 (released December 20, 2002), Pars. 6, 7.

margin. While it is argued that 900 MHz and 2.4 GHz have been a "tremendous success" given the wireless activity that has arisen there, more recent unlicensed allocations in 1.9 GHz (U-PCS in 1994), and 5 GHz (U-NII in 1997), and again in 5 GHz (2003), do not appear to have generated anywhere near the same level of utilization. Meanwhile, licensed CMRS operators are producing extraordinary levels of valuable service, as determined by consumer purchases. See Table 1. Given that the Interference Temperature would transfer spectrum space from the one (licensed) to the other (unlicensed), the relevant economic analysis must compare the social value of alternative uses of this particular space. A categorical endorsement of the "tremendous success" of unlicensed fails to achieve this.

Before embarking on that analysis, it is important to note why initial allocations for unlicensed use could prove far more valuable than subsequent allocations. Primary unlicensed bands (which we refer to as 900 MHz and 2.4 GHz) have largely provided short-range wireless applications not needing the assistance of network service providers. Commission mandates (particularly on power levels) form a reasonable substitute for coordination among users. In essence, the market is not needed to ration scarce spectrum access among competing claimants. And when a user does experience harmful interference (i.e., uses conflict, forcing a choice), usage can be adjusted without multi-party bargaining.

The examples illustrate. Remote controls, baby monitors, cordless phones, headsets, printer connections, fire alarms, and other devices requiring signals to travel through offices or households generate very limited, area-specific demands to use radio spectrum. Inexpensive devices allow such transmissions to be contained in small spaces, meaning that power limits effectively separate users. The applications to which the power limits apply are not substantially disadvantaged by such rules, in turn, because localized transmissions are best provided with low power. Congestion is naturally limited. Conflicts are further ameliorated by the fact that individuals, businesses, or organizations often internalize both the costs and benefits from adjusting use to avoid interference.

Mike Chartier, Director of Regulatory Policy for the Corporate Technology Group at Intel, explains the situation in personal terms:

> [M]y wife... discovered while using her lap-top in a room far away from the access point, that simultaneous use of our (expensive) 2.4 GHz phone would cause her internet connection to stop working. Accordingly we replaced the expensive 2.4 GHz phones with (cheaper) 900 MHz ones, problem solved. However later wanting the caller ID feature on the 2.4 GHz phone she reconnected it in a different location, trading off a smaller amount of interference for the added feature. This behavior is the epitome of an efficient Coasian firm- internalizing transactions costs and optimizing resources in a way neither regulation nor market transactions could achieve.[55]

[55] Mike Chartier, *Local Spectrum Sovereignty: An Inflection Point in Allocation,* Proceedings of the International Symposium on Advanced Radio Technologies, U.S. Dept. of Commerce, NTIA Special Publication SP-04-409 (March 2004) ["Chartier 2004"], p. 33.

In sum, wireless bandwidth contained entirely within an enterprise or household may be rationally allocated by the managers of the firm or the residents who live there. As scale increases, other local control mechanisms may – or may not – successfully perform this function. Landlords, office park developers, or homeowners' associations may establish networks for the joint use of tenants, for instance. Businesses quite commonly build and supervise use of wireless local area networks (WLANs) in the workplace. The information technology department is used to build and maintain corporate WiFi hotspots. This function involves both investing in infrastructure (access points and backhaul, for instance) and engineering solutions that reduce conflicts. Competing wireless networks are not permitted, and access to the corporate WLAN is restricted. Intel, for instance, explicitly restricts unauthorized use of unlicensed frequencies within its corporate office space:

> Failure to fulfill the above terms and conditions [*for non- IT WLANs*] will result in I.T.'s disconnecting and or taking possession of the Experimental W-LAN Access Points.[56]

Universities perform the same function on college campuses, where the demand for WLAN access is particularly intense due to high demand for access to databases and communications services, and the mobility of college students who travel between classes and activities rather than occupying offices. Conflicts would be relatively costly; to prevent them, universities protect "their" airspace by effectively privatizing the commons. Using their position as landlords, they attempt to assert local jurisdiction over unlicensed bands. The policy adopted by Carnegie-Mellon University demonstrates how this is done:

> While we will not actively monitor use of the airspace for potential interfering devices, we will seek out the user of a specific device if we find that it is actually causing interference and disrupting the campus network. In these cases, Computing Services reserves the right to restrict the use of all 2.4 GHz radio devices in university-owned buildings and all outdoor spaces on the Carnegie Mellon Campus.[57]

The regulatory mechanisms (low power, organizational control) that limit inter-user conflicts in unlicensed radio spectrum are not nearly so effective when signals travel further. Over broader geographic areas, additional users are involved, and transaction costs increase. No longer can a corporate IT Department impose an integrated solution enforced through company policy. To obtain the benefits of efficient systems using transmissions covering wider areas, businesses and households seek to use market mechanisms to manage conflicts between wireless users sharing radio spectrum.[58]

[56] Chartier 2004, pp. 32-3 (parenthetical in the original).
[57] Airspace Guideline for 2.4 GHz Radio Frequency at Carnegie Mellon University, as cited in Chartier, op cit., p. 5.
[58] The basic logic was first put forth in the classic analysis by R.H. Coase, *The Nature of the Firm*, 4 ECONOMICA 386 (November 1937).

With exclusively-assigned, flexible-use rights, decision makers create networks that optimize the mix of usage, typically via managing devices, price schedules, and service contracts. Without exclusively-assigned rights, the cost of reaching consensus prevents many efficient solutions from being implemented. Control breaks down when, for example, the 100-foot radius WiFi hotspot is replaced by a 3-mile radius PCS base station. No longer can a Starbucks owner impose a scheme to ration radio access.

Advanced wireless technologies are cited by some as the answer to this problem. Because newer systems are more effective at using small slivers of radio space at low economic cost, the congestion problem is said to be solved. This is false. Advanced technologies do allow more intense utilization of radio waves, but this simultaneously increases demand to access radio waves. Hence, the effect of new technology may well be to make airwave access rights *scarcer*, as scarcity is defined as a relationship between demand and supply.

The assertion that exclusive rights to spectrum are unneeded for efficient spectrum utilization relies on the observation of relatively heavy use in some unlicensed bands, and extrapolates that success to additional bands, citing the development of new technology as the justification for imposing unlicensed allocations more generally. The logic fails

(a) to understand where unlicensed use works, and where it does not; and, therefore,
(b) to understand the margins on which spectrum scarcity exists.

Here is an analogy. In a downtown business district, one may observe that parking spaces, metered during the day, are free after the stores close. This switch is clearly associated with shifting demands, which change scarcity conditions. One form of rationing (price), is relatively important where conflicts are relatively intense, but becomes less so when demand drops. Whereas spectrum scarcity may not be so intense when using cordless phones or wireless LANs, this does not imply that conflicts are absent when wireless Wide Area Networks (WWANs) are involved. Across large numbers of users, coordination between parties becomes considerably more important.

This can be seen in the claims made that unlicensed services should be allocated more radio spectrum. Conflicts in unlicensed bands are cited as detrimental by the providers of unlicensed services, and this congestion is used as the premise on which new bands should be allocated for unlicensed. But the logic is contradictory. Extending the use of unlicensed for services where congestion is problematic offers to expand the problem of inefficient spectrum use. The lack of coordination will continue to plague users, to the degree use is made of the additional frequency space. In specific terms, this is happening as unlicensed WWANs attempt to provide "last mile" services. "Wi-Fi is often portrayed in the media as a last-mile wireless solution, which it is not….," writes Pyramid Research. "That's where 802.16, or WiMax, fits in."[59] It is worth noting that promoters of WiMax, such as Intel, seek

[59] John Yunker, *Five WiFi Myths*, PYRAMID RESEARCH (June 11, 2003), http://www.pyramidresearch.com /info/wifi/gw030611.asp.

to deploy WiMax on licensed frequencies in populated (high demand) areas, in order to overcome coordination problems with unlicensed spectrum.[60]

This is vividly seen in pleas made to regulators by wireless Internet Service Providers (WISPs) attempting to provide broadband connectivity via unlicensed spectrum. WISPs complain about congestion with each other, as well as with unlicensed devices used by potential subscribers. Exclusively-assigned, flexible-use spectrum offers the opportunity such operators are requesting,[61] although the standard argument made is for the Commission to provide the benefits of licensed use while sparing established WISPs from bidding for licenses. One operator recently petitioned the FCC to impose a "Homestead Policy," under which property rights would be enjoyed by a few "unlicensed" WISPs:

> I own and operate a WISP (Wireless Internet Service Provider) in rural Southern Illinois. I provide services over the network I have built there that exceed the quality and varied uses seen in any other broadband based networks… This is not just coffee shop WiFi we are discussing… This type of highly engrained use of this technology in small towns and metro areas is not unique to Mt. Vernon, IL. These services are part of the infrastructure of our communities now on a worldwide scale. The aggressive adoption of these bands has come with little protections to WISPs and their high profile customers and is in danger of creating a disastrous implosion if nothing is done to remedy the impending interference hazards on the horizon. WISPs have no rights to the spectrum they use… I want to suggest a policy to help solve these issues and provide unlicensed use of this band simultaneously. I propose a new policy called the WISP Homestead Policy… Homestead status would be given to WISPs who register with the FCC and provide documentation proving active use… There would be no enforcement of license rights unless a homestead operator proves they have a claim to spectrum and that they are receiving interference from other sources. Part-15 devices that interfere with a homestead WISP operation that are not owned and operated by a homestead would be required to change channels or move their equipment to alleviate the interference. This would be the extent of the rights granted WISPs…[62]

[60] "In congested urban areas, licensed services may be the best way to proceed in order to encourage deployment, ensure optimal quality of service, and manage interference." Peter Pitsch, The Future of Radio Spectrum Policy, TECHNOLOGY@INTEL MAGAZINE (February/March 2004), p. 18; http://www.intel.com/ update/issue/tim0204.pdf.

[61] Stuart Benjamin, presenting evidence that congestion incurs serious inefficiencies on unlicensed bands, proposes greater reliance on licensed bands. Benjamin, *Spectrum Abundance*, op cit.

[62] John Scrivner, Mt. Vernon. Net, Inc., *WISP Homestead Policy Proposal For WISP Use of the ITFS Band,* Comment filed with Federal Communications Commission, WT 03-66 (March 19, 2004).

This view is echoed in numerous other FCC filings by those attempting to use unlicensed frequencies for "last mile" broadband, including this one:

> I would like to encourage the FCC to reallocate some spectrum for exclusive use of internet service providers or other deployers of outdoor fixed wireless broadband data networks…
>
> I would strongly discourage the FCC from allowing consumer products to use these frequencies, as they already have several different ISM bands to use (900 Mhz, 2.4 GHz, etc.)[63]

C. Benefits of Rival Allocations on the Margin

Spectrum allocation involves incremental choices. The success of a regulatory model in one instance does not necessarily imply success in the next. Whatever the experience with WiFi, cordless phones, or baby monitors, the value of additional unlicensed spectrum depends on *new* opportunities. Where the unlicensed allocation comes at the expense of licensed, as in the INTEM proposal where underlays become off-limits to licensees, the issue is one of alternative benefit streams. What would the licensed operator be able to accomplish with the right to control use in the underlay, versus the value of the uses made possible by the unlicensed rules?

The 2.4 GHz allocation for unlicensed spectrum has been followed by the U-PCS allocation of 20 MHz at 1.9 GHz in 1994,[64] the U-NII allocation of 300 MHz in the 5 GHz band in 1997,[65] and by 255 MHz in the 5 GHz band in 2003.[66] Subsequent experience with the use of these bands largely supercedes experience with the 2.4 GHz allocation in answering that question what value would likely be created by additional spectrum access for unlicensed devices?

Again, the built-in efficiency of exclusively-assigned frequency rights is that such questions can be answered by bidders in capital markets, and they tend to be better informed – and far quicker to adjust to new opportunities – than government policy makers. But in

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[63] Comments of Jeff Phillips, Rural Ramp (March 22, 2004), in Federal Communications Commission, WT 03-66. See also, in same docket, Comments of K. Sullivan (March 19, 2004), T. Stelle (March 22, 2004), Accel Net, Inc. (March 22, 2004), John Buwa, Michiana Wireless (March 22, 2004), and Reliable Internet Services (March 19, 2004).

[64] Federal Communications Commission, *Amendment of the Commissions Rules to Establish New Personal Communications Services*, GEN Docket No. 90-314, FCC 94-144 (released June 13, 1994), par. 26.

[65] Federal Communications Commission, *Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range*, ET Docket No. 96-102, FCC 97-5 (released January 9, 1997), par. 27.

[66] *See Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 03-122, FCC 03-287 (released November 18, 2003).

proposing to impose unlicensed underlays, the Commission pushes a market test to the side. Unfortunately, it does not replace this test with even an informed "command-and-control" evaluation of the opportunities likely to be available for additional unlicensed uses on the relevant policy margin. The omission of this inquiry strips the assertion that more unlicensed allocations serve the public interest of substance. This can be seen in the admission that many unlicensed users prefer to have access to additional licensed spectrum to meet their communications needs:

> A whopping 38 percent of [the National Telecommunications Cooperative Association's] members who responded to NTCA's 2003 wireless survey indicated that they are utilizing unlicensed spectrum to provide wireless services. . . While interference was not yet cited as a major problem among NTCA members completing the survey, many have indicated that they are seeing more and more interference from unlicensed devices. Therefore, they contend, *unlicensed spectrum is not a reliable method of providing wireless service to rural America. . . Despite the costs associated with licensed spectrum, NTCA members indicated that they would prefer more licensed spectrum to more unlicensed spectrum by a 71% to 29% margin.*[67]

There is nothing ironic about the fact that unlicensed users, or consumers of services provided by networks operating on unlicensed spectrum, may be far better served by additional EAFUS allocations. Indeed, a leading manufacturer of wireless "last mile" broadband equipment, Alvarion, believes that a proposal to allow 190 MHz of spectrum allocated to MMDS/ITFS at 2.5 GHz to be used more flexibly by licensees (moving towards the EAFUS model) is preferred to reallocating the frequencies for unlicensed use. "'There's really not that much [MDS/ITFS spectrum],' commented [Alvarion's Chief Evangelist Patrick] Leary. 'There's actually a lot more available in the unlicensed bands.'"[68] Alvarion has an interest in promoting new wireless investments in either licensed or unlicensed bands. Given existing allocations, however, the incremental value of exclusively-assigned spectrum is likely to generate more valuable economic activity.

The claim made by Alvarion is supported by evaluating marginal bandwidth made available for use under alternative regulatory models. A caveat is that there is no entirely reliable way to compare two distinct possible uses for spectrum. This, in fact, forms the argument for market allocation of radio spectrum. If estimates of the social value of bandwidth in alternative deployments were scientifically valid, then competitive market forces would not be necessary to reveal, through trial and error of investment choices, efficient solutions. Hence, the data simply inform rough guesses about rival values.

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[67] Comments of the National Telecommunications Cooperative Ass'n, WT Docket No. 02-381, at 11-12 (filed December 29, 2003) (footnotes omitted) (emphasis in original).

[68] Sweeney, *A Second Chance for MMDS,* BROADBAND WIRELESS ONLINE (September/October 2003), available at http://www/shorecliffcommunications.com/magazine/volume.asp?Vol=40&story=353.

Consider the marginal allocation for unlicensed use. The FCC has very recently made 255 MHz available in the 5 GHz band,[69] and it is too early to examine productive use of this bandwidth. In 1997, however, the FCC's U-NII proceeding allocated 300 MHz for unlicensed use.[70] Equipment has been sold for use in these bands, and sales revenues are available for the WiFi (WLAN) technology deployed at 5 GHz, 802.11a.[71] We take these data to offer information on the value of this unlicensed spectrum.

In Tables 1 and 2, available sales data for equipment using the 5 GHz unlicensed allocation are displayed (service revenues are de minimus). In 2003, about $180 million in equipment revenues were recorded for 802.11a technology, with the largest portion coming from user devices as opposed to network infrastructure.

TABLE 2. TOTAL U.S. REVENUE FOR 802.11A DEVICES

2000	2001	2002	2003	2004	2005	2006
$0.00	$4.40	$125.60	$176.60	$281.70	$351.40	$431.50

Notes & Sources:
Revenues obtained from *Wireless Weigh-In - 12/03* MORGAN STANLEY EQUITY RESEARCH (December 22, 2003), p. 13. Revenues are in millions. 2003 to 2006 revenues are estimates.

Alternatively, CMRS licensees have 189 MHz of allocated bandwidth at 800 MHz, 900 MHz, and 1.9 GHz.[72] Current supply-side valuations for marginal CMRS bandwidth are available. C Block PCS licenses won at auction in 1996 are now being sold by NextWave, given resolution of a long-running bankruptcy dispute, revealing market prices for bandwidth access under CMRS rules. Initial sales of 34 PCS licenses covering about 83 million pops indicate a market value of C Block licenses of about $2.15 per MHz per pop.[73]

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[69] Federal Communications Commission, *Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 03-122, FCC 03-287 (released November 18, 2003), par. 1.

[70] Federal Communications Commission, *Amendment of the Commission's Rules to Provide for Operation of Unlicensed NII Devices in the 5 GHz Frequency Range*, ET Docket No. 96-102, FCC 97-5 (released January 9, 1997), par. 27.

[71] "[802.11a is] an extension to 802.11 that applies to wireless LANs and provides up to 54 Mbps in the 5GHz band", webopedia.com, *802.11*, http://www.webopedia.com/TERM/8/802_11.html

[72] Recall that this bandwidth was identified as comprising the entire allotment of exclusively-assigned, flexible-use spectrum as of November 2002. See Kwerel and Williams (2002).

[73] The NextWave licenses are worth $8.4 billion. Legg Mason, *Nextwave-Cingular Deal: Near-Term Upside Potential for NextWave* (August 6, 2003). NextWave's licenses cover 166 million pops in total with an average 23.5 MHz. This implies $2.15 per MHz-Pop.

These valuations imply that carriers, to access 10 MHz of nationwide CMRS spectrum, would pay on the order of $6.0 billion (= $2.15*280,000,000*10). This is an estimate of the producers' surplus anticipated by service suppliers; total social value would be a substantial multiple of this. Greg Rosston shows that the ratio of consumers' surplus to producers' surplus in CMRS valuations is likely to be at least ten to one.[74] This implies a *marginal social value* of nationwide CMRS spectrum in excess of *$5 billion per MHz.*

Annual equipment expenditure data (for 5 GHz unlicensed) cannot be directly compared to lump sum present values (for 2 GHz CMRS licensed), although various transformations can capitalize the annual data or annualize the present values. Yet, the magnitudes are not close enough to warrant further inspection. By any reasonable measure, consumer demand is much higher to gain access to additional licensed frequencies under CMRS rules.

This is not surprising. First, the amount of CMRS spectrum is tightly constrained given its extremely widespread use. With over 150 million wireless subscribers speaking over 700 billion minutes per year, and with considerable demand for new and faster data services, which carriers are attempting to efficiently provide over integrated systems (e.g., 1X, EV-DO, EDGE), demand for additional CMRS capacity is intense. Second, the most compelling applications of unlicensed use are highly localized. Given the control that a user exerts in her immediate area, the 900 MHz and 2.4 GHz allocations offer abundant opportunities for deployment. Hence, for incremental short-range devices, existing ("inframarginal") unlicensed bands satisfy most demands.

Third, demands for additional bandwidth are primarily driven by wider area applications, where licensed spectrum is a relatively effective substitute. Competitive EAFUS licenses yield the opportunity to coordinate wide area usage at low cost. It is for this reason that demand for additional CMRS spectrum is so high; even in the face of hundreds of MHz of new unlicensed bands, carriers still seek to utilize exclusively-assigned rights, and are willing to spend billions of dollars to secure them. It is also the driver behind strategic decisions to design WiMax and other "4G" wireless broadband technologies as "licensed" technologies.

As contemplated in the INTEM Notice, underlays would be transferred from licensees, including CMRS licensees, to unlicensed users. By any reasonable measure, this trade-off will create little incremental value, as seen in the very modest use of the most recent unlicensed band allocations. Alternatively, it will reduce spectrum access in CMRS bands where the incremental social value of bandwidth likely much exceeds $5 billion per MHz for nationwide spectrum. The evidence in today's marketplace strongly suggests that applying the Interference Temperature proposal to the CMRS bands would destroy social value rather than create it.

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[74] Gregory L. Rosston, *The Long and Winding Road: The FCC Paves the Path with Good Intentions*, Stanford Institute for Economic Policy Research, SIEPR Discussion Paper No. 01-08 (December); http://siepr.stanford.edu/papers/pdf/01-08.pdf.

IV. EFFICIENT SHARING OF LIBERAL LICENSE RIGHTS

The INTEM Notice concedes that administrative allocation of radio spectrum today produces inefficient results, but claims that: "In the past, this model generally served well to control interference and to facilitate effective use of the spectrum in environments in which the specific services and operating technology were stable and well defined."[75] Upsetting this happy state of affairs, says the Notice, are changes in the laboratory and the marketplace: "However, the dramatic increases in the overall demand for spectrum based services, rapid technical advances in radio systems, in particular the introduction of various advanced modulation techniques, the increased use of spectrum for mobile services, and the need for increased access to the limited supply of spectrum in recent years are straining the effectiveness of the Commission's longstanding spectrum policies in dealing with some allocations and applications."[76]

But the central planning methods used to allocate radio spectrum were always inefficient. While interference between users may have been limited, the social costs of preventing conflict have been far too high. As a consequence, new technologies have been delayed or deferred, widespread under-utilization of bandwidth has been observed, and substantial consumer gains have been sacrificed.[77] Economic research has demonstrated inefficient use of AM band airwaves in the 1920s and 1930s,[78] FM radio technology in the

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[75] INTEM Notice, p. 3.

[76] INTEM Notice, p. 3.

[77] Ronald H. Coase, *Evaluation of Public Policy Relating to Radio and Television Broadcasting: Social and Economic Issues*, LAND ECONOMICS 161 (1965); Harvey J. Levin, THE INVISIBLE RESOURCE: USE AND REGULATION OF THE RADIO SPECTRUM (1971); Harvey J. Levin, *New Technology and the Old Regulation in Radio Spectrum Management*, 56 AM ECON REV 339 (1966); Harvey J. Levin, *The Radio Spectrum Resource*, 11 J L & ECON 433 (1968); Douglas W. Webbink, *Radio Licenses and Frequency Spectrum Use Property Rights*, 9 COMM & L 3 (June 1987); Douglas W. Webbink, *Frequency Spectrum Deregulation Alternatives*, Federal Communications Commission, OPP Working Paper No. 2 (Oct. 1980); Ithiel de Sola Pool, TECHNOLOGIES OF FREEDOM (1983); Bruce Owen and Steve Wildman, VIDEO ECONOMICS (1992); Reed E. Hundt and Gregory L. Rosston, *Spectrum Flexibility Will Promote Competition and the Public Interest*, IEEE COMM MAG 40 (December 1995); Peter Huber, Law & Disorder in Cyberspace (1997); Gregory L. Rosston and Jeffrey S. Steinberg, *Using Market-Based Spectrum Policy to Promote the Public Interest*, FCC Staff Paper (Jan. 1997), http://www.fcc.gov/Bureaus/Engineering_Technology/Informal/spectrum.txt.

[78] Thomas W. Hazlett, *The Rationality of U.S. Regulation of the Broadcast Spectrum*, 33 J. LAW & ECON. 133 (April 1990); Robert W. McChesney, TELECOMMUNICATIONS, MASS MEDIA, & DEMOCRACY 12-37 (1994); Thomas W. Hazlett, *The Wireless Craze, the Unlimited Bandwidth Myth, the Spectrum Auctions 'Faux Pas,' and the Punchline to Ronald Coase's 'Big Joke': An Essay on Airwave Allocation Policy,* 14 HARV. J. L & TECH 335 (Spring 2001), Section VIII-A.

1930s, 1940s, and 1950s,[79] the broadcast TV band from the 1940s until the present,[80] and cellular telephony in the 1950s, 1960s, 1970s and 1980s.[81] In each instance, bandwidth was allocated by the Commission (or its predecessor, the Federal Radio Commission) such that consumers were given far less access to wireless services than less regulated markets would have offered. Long before the advent of advanced digital wireless systems, the FCC's spectrum allocation regime had become a textbook example of anti-consumer regulation.[82]

The twin claims that the regulatory structure was well suited to a previous era, but must now change due to new circumstances, obscures precisely the problems in spectrum allocation that should be fixed. This results in the Commission seeking to impose – by *command* – its spectrum allocation choices on the marketplace.

The historical lesson that the Commission should heed is one that previous Commissions learned and, by incorporating, improved consumer welfare. Where regulators have broadly extended spectrum use rights to licensed operators, productive wireless enterprises have sprouted. This result is clearly visible in the small part of the radio spectrum where the Commission has granted wireless operators the most flexible and extensive rights to use bandwidth, in commercial mobile radio services (CMRS). Licenses for these services are allocated approximately 189 MHz, or about 7% of the 2778 MHz of prime bandwidth located below 3 GHz.[83]

A. Intense Use of CMRS Spectrum

Explicitly departing from traditional administrative controls, a series of Commission rule makings in cellular, ESMR (enhanced specialized mobile radio), and PCS (personal communications services) effectively established a regulatory regime in which operators determine how bandwidth allocated licenses is utilized, freely selecting technologies, services, and business models. Enormous social value has been created. In 2003, CMRS subscribers paid about $88 billion for wireless telephone service.[84] A rough approximation of aggregate consumer surplus (abstracting industry profits, which are also properly included in calculating social value) is suggested as one half of industry revenues, or about $44

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[79] Lawrence Lessing, MAN OF HIGH FIDELITY: EDWIN HOWARD ARMSTRONG (1954); Stanley M. Besen, *AM versus FM: The Battle of the Bands*, 1 INDUS. & CORP. CHANGE 375 (1992).

[80] *See* Harvey J. Levin, Federal Control of Entry in the Broadcast Industry, 5 J L & ECON 9 (1962); FACT AND FANCY IN TELEVISION REGULATION (1980); Noll, Peck and McGowan, *Economic Aspects of Television Regulation*, Brookings Institution (1973); B. Owen, J. Beebe and W. B. Manning, Jr., *Television Economics*, D.C. Heath (1974); Thomas W. Hazlett, *The U.S. Transition to Digital Television: Time to Toss the Negroponte Switch*, AEI-Brookings Joint Center for Regulatory Studies Working Paper 01-15 (November 2001).

[81] George Calhoun, DIGITAL CELLULAR RADIO (Artech House, 1988).

[82] Thomas Sowell, KNOWLEDGE AND DECISIONS (Basic Books, 1980), pp. 170, 195-6.

[83] Kwerel and Williams (2002), pp. 27, 32.

[84] Merrill Lynch, WIRELESS GLOBAL MATRIX (2003).

billion.[85] In present value terms, assuming a (high) social discount rate of 10%, and annual revenue growth of five percent, the capitalized value of the consumer benefits in the wireless phone market alone (ignoring producers' surplus and multiplier effects) is approximately $900 billion.

The spectrum used by CMRS licensees is intensively shared, producing extremely large social benefits. Over 150 million subscribers utilize the six national networks (and additional regional ones). Customers have access not to narrow slices of bandwidth in isolated locations, but are able to access multiple channels in "broadband" wireless networks all across the country, 24/7. In 2003, about 90 million mobile phone network handsets were sold in the United States.[86] Each is both a transmitter and a receiver, and coordination of service among users is extremely complicated. Networks are created and maintained by the construction, interconnection, and maintenance of over 150,000 base stations.[87] Mobile phone usage was over 800 billion minutes in 2003,[88] at prices averaging just 11 cents per minute in 2003, down from 57 cents in 1993.[89]

Productive spectrum sharing follows from the incentives and opportunities associated with flexible, exclusive use spectrum. Market forces compel wireless carriers to efficiently utilize bandwidth so that additional users, and revenues, can be accommodated. Network operators have strong financial motivation to balance quality of service against cost considerations; if done successfully, selected trade-offs produce competitive superiority. Solutions are engineered by rival carriers to weigh gains and losses from increased sharing, and these considerations are complex. They involve power levels and battery life, blocked call ratios and base station investments, handset costs and customer affordability. To make the best choices, economic data are constantly monitored. Changes in input markets – most notably, technological innovation – as well as emerging options in output markets – most notably, new applications – force wireless carriers to continuously re-evaluate ways to increase the value of the radio spectrum allocated to their licenses. These experiments are not discrete, or casually viewed. Rather, operators strategically monitor market developments and network performance to locate additional profit opportunities.

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[85] See Footnote 42. In the case of the mobile phone market, the 50% rule of thumb may be very conservative. In Figure 3, the ratio of consumer surplus to producer surplus is 91%.

[86] Calculated from $13.8 billion cost of handsets to carriers divided by an average wholesale price in the U.S. of $154. Mike Dano, *Phone Subsidies Alive and Well*, RCR Wireless (January 5, 2004), p. 1.

[87] CTIA, *CTIA Semi-Annual Data Survey Results Book, 1985-2003*, http://www.wow-com.com/images/survey/2003_endyear/752x571/Cell_Sites_Dec03.jpg

[88] CTIA, *CTIA Semi-Annual Data Survey Results Book, 1985-2003*, http://www.wow-com.com/images/survey/2003_endyear/752x571/MOU_Dec03.jpg

[89] Calculated from CTIA, *CTIA's Wireless Industry Indices, August 2002*, Table 107, CTIA, *CTIA Semi-Annual Data Survey Results Book, 1985-2003*, http://www.wow-com.com/images/survey/2003_endyear/752x571/MOU_Dec03.jpg and CTIA, *CTIA Semi-Annual Data Survey Results Book, 1985-2003*, http://www.wow-com.com/images/survey/2003_endyear/752x571/Annual_Table_Dec_2003.jpg

The FCC has recognized that the flexible use policy in CMRS has produced extensive social benefits. For instance, the rules governing PCS licenses created 'overlays' which allowed new licensees to either move incumbent users (through negotiated relocations) or engineer systems to avoid interfering with existing communications.[90] Granting the rights to use spectrum space to a particular party creates incentives to deploy efficient technology, because financial gains accrue to the investor.

Technology does not dictate the legal regime. Spectrum is beneficially shared by tens of millions of wireless users in the CMRS market largely due to regulatory forbearance – granting wide latitude to licensees to determine spectrum use – by the FCC. When allowed to effectively control the use of radio frequencies, networks operators devote substantial resources to squeezing additional services out of given bandwidth. Personal digital assistants (PDAs) are connected to online services by millions of wireless subscribers, who use these pocket computers for email, web browsing, instant messaging, and voice calls. Yet, there are no FCC "PDA Rules." Instead, virtual networks emerged spontaneously, sharing the spectrum allocated to wireless networks. Similarly, high-speed data services are provided directly by wireless operators over spectrum also used to provide voice calls. Likewise, resellers such as Virgin or TracFone account for a substantial part of retail sales.[91] These arrangements share billions of minutes of network time. Other networks use the spectrum allocated to wireless operators, including the On Star service, which maintains access through the Verizon Wireless network.

B. The Analog-to-Digital Transition in CMRS

The efficiencies of coordinating shared spectrum use through exclusively-assigned, flexible-use licenses has been vividly demonstrated in the mass migration of cellular phone users from analog to digital systems. Cellular telephone licenses for the 306 largest markets, issued in 1983-86, mandated that all service providers use the analog AMPS standard.

Cellular service became much more popular than forecast. By the late 1980s, it became obvious that the limitations of the AMPS standard made it difficult to meet wireless phone service demand in the largest markets. Hence, the FCC permitted cellular carriers to use other technologies. This flexibility signified an important break with tradition, as it allowed market forces to dictate technology choices.

The industry created a digital standard known as Time Division Multiple Access (TDMA). The design process was demanding. In addition to the challenge of making digital voice work over the urban multi-path channel, the new system had to be phased in

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[90] *See* Peter Cramton, Evan Kwerel, and John Williams, *Efficient Relocation of Spectrum Incumbents*, 41 J L & ECON 647 (Oct. 1998).

[91] Five percent of mobile phone subscribers purchase service from resellers. See Federal Communications Commission, *Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services, Eighth Report*, WT Docket No. 02-379, FCC 03-150 (released July 14, 2003), Table 2.

incrementally. That is, it had to share licensed spectrum, running simultaneously with analog, permitting AMPS service to continue while phasing in digital service. This transition would yield enormous benefits, as TDMA tripled capacity over analog with superior voice quality. But, given the large embedded base of analog users, the path was difficult.

An upstart competitor Qualcomm observed the liberalization of cellular, and entered the technology contest. It developed a Code Division Multiple Access (CDMA) digital wireless system and demonstrated it in late 1989. Some carriers selected TDMA, some selected CDMA, some selected TDMA then switched to CDMA. When PCS licenses were issued in 1995, the standards battle continued, and grew to include a third rival imported from Europe – GSM.

Some believe CDMA has emerged victorious. TDMA is being abandoned and all 3G systems are based on CDMA for the radio link. The experimentation and testing of the two designs was conducted by licensed wireless carriers. Their investments – over $136 billion in book value through June 2003[92] – drove the development and deployment of both national wireless networks and the technologies they utilize. The standards competition drove a trial and error process that rigorously tested the available options. Digital systems have now expanded capacity roughly ten-fold, while simultaneously improving quality and reliability. They also deliver high-speed data and text messaging services.

Three crucial regulatory issues arise in this episode. The first is that relaxation of the government technology mandate spurred a vigorous, socially valuable competition between advanced wireless technologies. Second, this fertile technology battleground was nurtured in licensed spectrum. That operators were able to control swaths of radio space gave them incentives to invest aggressively. The newly created capacity could then be used to increase services, benefiting users and the carrier.

Third, extremely complex spectrum-sharing arrangements, when distinct technologies ran side by side in the same bands, were smoothly executed due to proper economic incentives. Carriers profited by making the move to digital painless for analog customers, subsidizing handsets and promoting new digital services with attractive pricing and service plans. The carriers benefited from these investments, capturing additional revenues due to the larger capacity yielded by a more spectrum-efficient system. With exclusively-assigned rights, coordination of a very complicated upgrade of the "embedded base" was achieved.

C. Investment Incentives and Spectrum Sharing

Enhanced spectrum sharing in EAFUS bands does not stop with the advent of digital cellular. The pressure to increase spectral efficiency is relentless. This is seen in the evolution of a CDMA system such as deployed by Verizon Wireless. The transition from analog to digital technologies greatly expanded utilization of spectrum, as discussed above,

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[92] CTIA, *CTIA Semi-Annual Data Survey Results, June 1985 - June 2003*, http://www.wow-com.com/pdf/MidYear_2003_survey.pdf.

when analog cellular was upgraded to the digital IS 95 standard beginning in 1996.[93] IS-95 is primarily a voice standard and can accommodate relatively low data rates, initially, just 14.4 kbps.[94]

Verizon Wireless then upgraded its CDMA network to 1xRTT technology beginning in the first quarter of 2002. Today, it covers virtually all system cell cites,[95] allowing data speeds of up to 144 kbps, with 40 to 60 kbps typical.[96] The next generation technology, Evolution – Data Optimized, or EVDO technology, is now being deployed. EV-DO can provide downstream data rates of over 2 mbps,[97] with 300 to 500 kbps typical, and upload data rates similar to 1xRTT.[98] Verizon Wireless launched EV-DO service in two markets in the fall of 2003, with national build-out proceeding in 2004.[99] The upgrade to EV-DO is reported to cost $1 billion in network infrastructure improvements.[100]

The digital upgrades to IS-95, IxRTT and EV-DO each involved substantial investments in networks and customer equipment. Carriers, in fact, subsidize telephone handsets for subscribers – about three fourths of the approximately $13 billion spent on mobile phones in the U.S. in 2003 was spent by carriers.[101] This strategy distributes more spectrally-efficient radios throughout their networks. In sum, upgrade investments are seen to create productive spectrum space, permitting more intense use of the licensed radio spectrum shared by millions of subscribers.

V. THE COST OF REASSIGNING UNDERLAY RIGHTS BELOW A CMRS LICENSEE

Should unlicensed underlays be inserted in bandwidth used by a licensed CMRS operator, aggregate noise in the band will increase as suggested in the INTEM Notice's Figure 1. This will have serious economic consequences where it reduces the capacity of existing wireless service providers. This will predictably occur where licensed operators have been given the flexibility (and, therefore, economic incentive) to make productive use of low power emissions – specifically, in CMRS bands. Of course, operator might well

93 Cellco Partnership SEC 10-K (2003), p. 7.
94 Financial Express – The Evolution of Mobile Communications Technologies, December 24, 2002.
95 Cellco Partnership SEC 10-K (2003), p. 7.
96 Cellco Partnership SEC 10-K (2003), p. 7.
97 Financial Express – The Evolution of Mobile Communications Technologies, December 24, 2002.
98 Cellco Partnership SEC 10-K (2003), p. 7.
99 Cellco Partnership SEC 10-K (2003), p. 7.
100 Dan O'Shea, *National EV-DO Plan Reflects Capex Renewal*, TELEPHONY ONLINE (Jan. 12, 2004), http://telephonyonline.com/microsites/magazinearticle.asp?mode=print&magazinearticleid=189891&releaseid=&srid=11357&magazineid=7&siteid=3.
101 Mike Dano, *Phone Subsidies Alive and Well*, RCR Wireless (January 5, 2004), p. 1.

respond with increased infrastructure investment or other measures to regain some (or all) of the lost capacity. Such improvements are not costless.

In what follows we will report estimates of reductions in wireless network coverage and capacity associated with increasing levels of noise that might be permitted under the INTEM proposal. Those estimates are translated into economic values that quantify the costs imposed by unlicensed underlays that raise noise levels in a licensed band. These estimates have been reported to us by V Comm, a wireless engineering firm, and relate to a hypothetical CMRS licensee deploying Code Division Multiple Access technology.[102] Other systems may tolerate noise differently. In addition, different firms or organizations could well produce a different set of estimates even for the same technology. The essential point of this exercise is to show that the costs of increased noise may be quite substantial, and that the assumption that they are trivial (implicit in the FCC's INTEM Notice) is unwarranted. The Commission should engage in fact finding to explore cost parameters; here we present one preliminary approach for doing so.

A. Capacity Losses from Increased Interference

Four scenarios are considered, each corresponding to a distinct level of increased noise over the existing noise floor. Those four "noise increments" are: 0.33 dB, 0.5 dB, 1 dB and 3 dB. To put these in perspective, a 0.33 dB increase in noise raises the noise floor under 10%, while a 3 dB increase approximately doubles the noise floor.

The effect of increased noise on a mobile phone system can be measured in at least three dimensions. First, the increase in interference can be represented as a reduction in geographic coverage area, holding call volumes per cell site constant. The geographic impact depends on how spectrum is utilized, intensity varying with population density. Consequently, noise effects on capacity differ in rural, suburban and urban areas. Second, increased interference can be represented as reduced capacity, holding the coverage of the system constant. This measures the impact of the added noise if the carrier does nothing to respond to the interference and continues to serve its original contour. Third, the damage of the incremental interference can be quantified by the increase in the number of cell sites needed to maintain original coverage and capacity.

Estimates produced by the three approaches, for each of the four noise increments, are reported in Table 3. These results are based on V Comm's analysis of a generic nationwide mobile telephone network that uses CDMA technology.

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[102] Comments of V-Comm, L.L.C., *In the Matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands,* ET Docket No. 03-237 (April 5, 2004) ["V-Comm 2004"].

TABLE 3. CDMA NETWORK CAPACITY LOSSES FROM INCREASED NOISE						
	Increase in Noise (dB)	Coverage Reduction			Capacity Reduction	Increase in Cell Sites
		Rural	Suburban	Urban		
Case 1	0.33	5%	5%	4%	5%	5%
Case 2	0.5	8%	7%	6%	8%	8%
Case 3	1	15%	13%	12%	16%	18%
Case 4	3	38%	35%	32%	61%	111%

Source: V-Comm 2004, Tables 2 and 5.

B. The Economic Costs and Benefits of Increased Interference

The reduced capacity estimates can be translated into economic costs in two different ways. First, reduced capacity can be measured in terms of the losses stemming from reduced usage of the current network. Second, we can calculate the costs to a network operator of recovering the capacity lost from the increased interference.

Mobile phone operators continuously invest capital and incur additional operating expenses to expand the capacity of their networks. Because network capacity is costly, mobile phone operators have a strong incentive to deploy that capacity only as it is needed. Consequently, there is a fairly tight relationship between a mobile phone system's capacity and its usage.

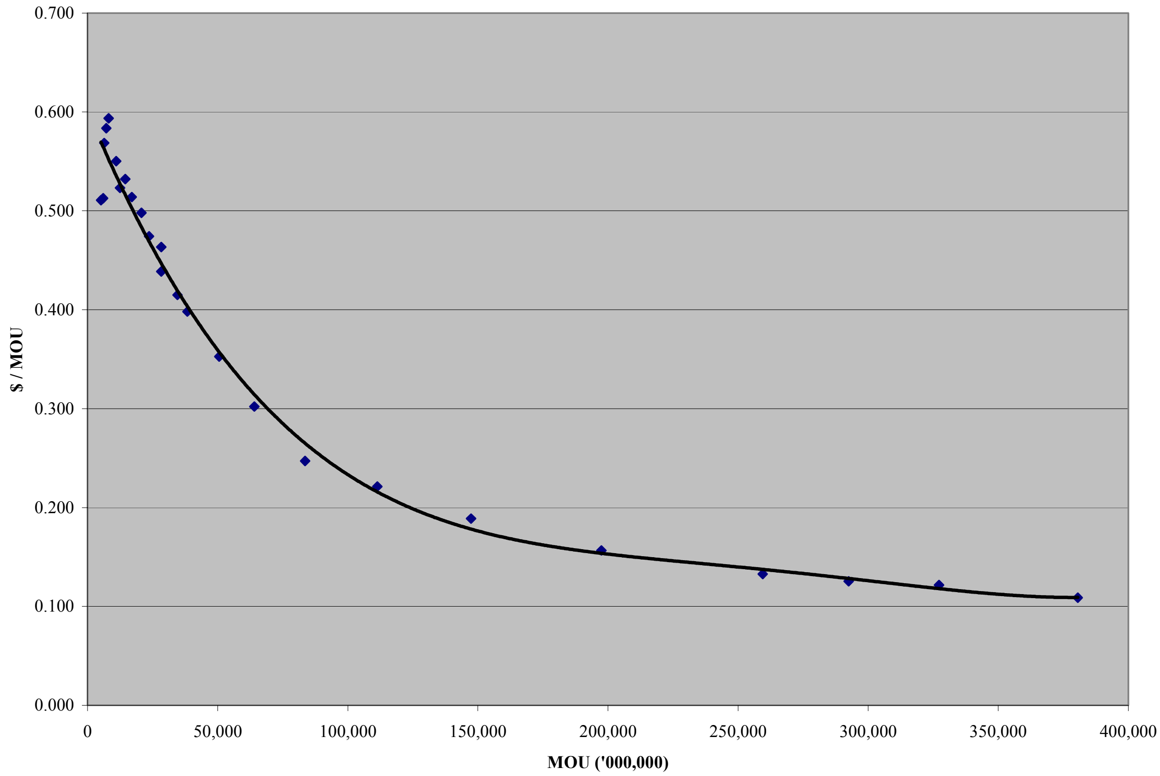
The connection between system capacity and system usage can break down if the network has minimum size constraints that require more capacity than is used. To be economically efficient, a cell can only be so large. Consequently, there is a minimum amount of infrastructure needed when a system is built. In some cases, typically in rural areas where usage is sparse, a cell may be underused such that a reduction in capacity of the system will not impact users. Estimated capacity reductions in Table 3 takes these variations into account.

Capacity. One way to measure the economic costs of a reduction in capacity would be to start with a fully specified demand function for mobile phone usage. Alternatively, a conservative estimate of the price-demand relationship can be observed using historical data. Figure 3 below represents the relationship between the average price per minute for mobile phone services in the US and the aggregate number of minutes of mobile phone use, in six month intervals, between June 1991 and June 2003.[103] Using the curve in Figure 3 to measure the impact of reduced capacity is a conservative approach because the short run demand curve for mobile phone usage is very likely to be steeper than the long run price-quantity relationship. This is because wireless phone demand tends to shift outward over

[103] CTIA, *CTIA Semi-Annual Data Survey Results, 1985-2003* (November 2003), Tables 28, 29 and 110.

time as service quality improves, handsets get better, and people become more accustomed to making mobile phone calls. Steeper short-run demand curves imply that our approach considerably understates the consumer surplus lost due to interference.

FIGURE 3: PRICE/MINUTE AND MINUTES OF USE
U.S. MOBILE PHONE MARKET, 1991-2003[104]



Reductions in usage translate into reduced revenues, leading to losses by carriers (Producers' Surplus [PS]), and reduced benefits enjoyed by consumers (Consumer Surplus [CS]). Estimated revenue reduction equals the reduction in capacity times the price paid for that capacity, which we set equal to 10.9 cents per minute of use (MOU) (the price recorded in the latest data – June 2003). This reduction in revenues overstates the value of lost sales to carriers, because the carriers may save some costs by not serving those minutes. So we estimate lost PS by multiplying lost revenue by 0.313, reflecting (approximately) the mean operating cash flow ratio of U.S. wireless carriers. CS, on the other hand, is the sum of benefits received by mobile phone customers over and above what they pay for service. It is calculated, in Figure 3, as the area between the historical price-quantity curve and 10.9 cents.

[104] Minutes of Use are obtained from CTIA, *CTIA Semi-Annual Data Survey Results, 1985-2003* (November 2003), Tables 28, 29. Total Service Revenues are obtained from CTIA, *CTIA Semi-Annual Data Survey Results, 1985-2003* (November 2003), Table 110.

Table 4 reports the reduction in both PS and CS for the four interference increments, estimates which apply to one hypothetical nationwide CDMA carrier.[105]

TABLE 4. ANNUAL ECONOMIC LOSS FROM REDUCTION IN CAPACITY FOR ONE CDMA CARRIER FACING INCREASED INTERFERENCE
($ BILLIONS)

	Reduction in capacity	Reduction in Rev	Reduction in PS	Reduction in CS	Total Annual Welfare Loss
Case 1	5%	$0.573	$0.179	$0.002	$0.181
Case 2	8%	$0.917	$0.287	$0.008	$0.295
Case 3	16%	$1.833	$0.574	$0.066	$0.640
Case 4	61%	$6.989	$2.188	$1.757	$3.944

Notes and Sources: MOU and price data from Figure 3. Assumes representative carrier has average of the big 6 carriers' cell cites. Calculates representative carrier's cell cites as a proportion of total cell cites, or 13.6% of national network. Reduction in PS is calculated as 31.3% of the reduction in revenues. This percentage is estimated using the average EBITDA to net revenues ratio for AT&T, Cingular, Nextel, Sprint PCS and Verizon Wireless. Data obtained from Smith Barney CitiGroup, *Still Standing – Initiating Coverage of the Tower Industry* (January 5, 2004), Fig. 171, p. 180.

Remediation. An alternative measure of the economic costs of increased interference focuses on the incremental capital and operating costs a network operator incurs to maintain network performance. This analysis takes into account different usage patterns in rural, suburban and urban markets, and assumes that the impact of interference on the system is measured in terms of coverage in rural areas, capacity in urban areas, and a mix of either in suburban markets.

Table 5 below reports the increased capital and operating costs for a CDMA network operator to overcome the harm from increased interference. The calculations assume 37.5 million subscribers, cost per cell site equal to $2 million, associated annual operating expenses are $100,000, and capital will last 8 years.

[105] A reduction in usage would, ceteris paribus, be accompanied by an increase in prices. That increase in prices would cause a transfer of revenue from consumers to producers of the remaining mobile phone service still purchased. That transfer, however, does not represent a welfare loss to society and is unaccounted for here.

Table 5. Increased Capital and Operating Costs for a CDMA Carrier Faced with Increased Interference ($ Billions)					
	Reduction in capacity	Increased capital expenditures	Increase annual capital amortization	Increased annual operating expenses	Increased cost per subscriber
Case 1	5%	$2.2	$0.3	$0.1	2%
Case 2	8%	$3.5	$0.4	$0.2	3%
Case 3	16%	$7.4	$0.9	$0.4	6%
Case 4	61%	$45.7	$5.7	$2.3	36%

Source: V-Comm 2004, Tables 6, 7. Annual capital amortization assumes 8 yr. asset life and zero discount rate.

These estimates are conservative, particularly for the lower interference increments. As projections, they are subject to further verification. But even under the most favorable (lowest noise level) scenarios, the impact on CDMA systems is not insubstantial, imposing estimated annual costs in the hundreds of millions of dollars. Higher noise levels would prove, of course, even more damaging to consumers and suppliers of CDMA network services.

Benefits of Unlicensed Underlays. Benefits to unlicensed users would have to be very substantial to offset the economic damage associated with increased levels of interference. But beyond the 900 MHz and 2.4 GHz unlicensed bands, use of unlicensed bandwidth has not proven robust. When compared to the high value place on marginal CMRS spectrum, use of these bands is extremely limited. Hence, for the Commission to transfer substantial radio space from CMRS licensees to unlicensed underlay users would be to place a huge wager that demand patterns not evident in recent unlicensed allocations materialize, offsetting quite substantial costs imposed on cellular consumers and licensees.

VI. An Experiment for Market Based "Unlicensed" Allocations

A. The EAFUS model has been successfully tested.

The INTEM Notice has called for experiments to test the INTEM concept in practice.[106] That the Commission argues for more information before broadly implementing the Interference Temperature concept is appropriate. Yet, the FCC, rather than seeking to construct experiments, should first recognize the factual record that exists. Exclusively-assigned, flexible-use spectrum rights have demonstrably achieved just the innovative band sharing the INTEM Notice heralds. This record includes the ability to upgrade technologies, to relocate users, and to effectively economize on the use of radio spectrum. Before embarking on more limited tests, the Commission should seek to incorporate these far-reaching marketplace results in its analysis.

[106] INTEM Notice, par. 30.

In reality, the primary source of information about how to best create and distribute wireless options comes from the ongoing experiments staged by actual users, interacting with actual suppliers, in actual markets. Given rules that yield incentives for productive spectrum use, competitors experiment constantly with technologies, business models, pricing plans, and spectrum sharing arrangements. This trial and error process prompted AT&T Wireless to offer a "Digital One" plan beginning in 1998, and brought its rivals to rush to offer similar plans – providing just one of many successful marketplace experiment widely touted by the Commission.[107] The constant pressure by wireless carriers to introduce new applications, from PDA connectivity to high-speed broadband for mobile laptops, involves experimentation on a vast number of margins – from network infrastructure changes, to marketing, to pricing, to user-friendly software or device interfaces, to performance in multidimensional qualities (speed, ease of use, reliability).

In the INTEM proceeding, the market data being generated by these ongoing experiments should provide a rich source of information to policy makers. Experience with the introduction of advanced wireless technologies does not, for instance, require a redeployment of spectrum space from licensed to unlicensed use. Any additional results from constructed regulatory experiments should be evaluated in light of these data.

B. An Alternative Policy Experiment: Overlays with Expanded Secondary Assignment Flexibility

Policy experiments may well shed light on the questions raised by the Interference Temperature concept. Surely, a properly designed test could potentially be quite helpful. Hence, we offer an experiment to chart the results of a "marketplace interference temperature." In select bands, an easily designed policy could be launched. Using the regulatory structure created for PCS overlay rights, the Commission defines exclusively-assigned, flexible-use spectrum rights giving licensees the right to use unoccupied radio space in the band with minimal regulatory constraints. Spectrum would then be allocated to competing licenses, ensuring bandwidth per license is sufficient to allow economies of scale and scope. Licenses could then be assigned by competitive bidding.

Winning rights holders would become band managers, and would have economic incentives to promote efficient spectrum use. This would encompass high power or low power systems, trading off consumer preferences for bandwidth, coverage, convenience, diverse applications, and cost. This optimization would extend to customer equipment and network infrastructure. Market forces could then create sharing rules that allowed efficient access to frequencies by multiple users. If sophisticated technologies that simultaneously, or

[107] "The Commission previously concluded that operators with larger footprints can achieve economies of scale and increased efficiencies… Such benefits permit companies to introduce and expand innovative pricing plans such as digital-one-rate ("DOR") plans, reducing prices to consumers." Federal Communications Commission, *Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services, Fifth Report*, FCC 00-289 (released August 18, 2000).

intermittently, transmit are worth their cost to customers, band managers would seek to provide them or to lease access to those who would. If, on the other hand, less expensive applications that operate best on uncontested frequencies were better in the eyes of consumers, the profit-maximizing band manager would tend toward that offering. Paying incumbent users (grandfathered to operate in the band) to deploy alternative transmission schemes, say, substituting fiber optic lines for wireless, or using less crowded bands, is just one of a myriad number of ways to "share" spectrum, and a band manager has strong financial incentives to select the efficient path.

Two important innovations could be implemented as part of this experiment. First, the Commission should create rules for these band managers that extend the opportunities for spectrum leasing in the Secondary Markets proceeding.[108] Instead of limiting reassignments of use rights to parties filing for certification and, in some cases, imposing up to 21-day waiting periods, the Commission should establish simple liability rules. Licensees would remain responsible for out-of-band emissions caused by devices intended to access their frequencies, yet still be able to assign rights to third parties to use allocated spectrum without any regulatory transaction cost. That would enable overlay licensees to configure devices, applications, and networks such that low power devices, including agile radios opportunistically accessing unutilized spectrum space, could operate as envisioned by the INTEM Notice in underlays. Through market negotiations with manufacturers of radio equipment, such accessibility could be seamless to the customer: device purchases would be bundled with spectrum purchases.

Second, the FCC should consider participating in the license auction. Purchasing one or more rights would allow regulators to use spectrum for 'open access' or other types of use, but in a transparent manner in which social opportunity costs are visible.[109] If the Commission determines that allocating more spectrum for unlicensed use is in the public interest, "paying" the market price should be worth it.[110] This logic is given by Kwerel & Williams, who suggest that bands set aside for unlicensed use at least be procured by a bid tendered by the government in an open auction process: "If there is a continued desire as a matter of public policy to provide spectrum for such devices on a 'free' basis, the FCC itself might purchase the spectrum in the auction… This would have the advantage of making the opportunity cost of such allocations more explicit."[111]

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[108] Federal Communications Commission, *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, WT Docket No. 00-230 (Released October 6, 2003).

[109] It is crucial that the rights be broadly defined. If Commission rules create very narrow economic opportunity for use of allocated airwaves, the license price will not reflect the true economic cost of the associated bandwidth.

[110] The payment would not come from tax revenues, as the FCC is the auctioneer. It would win a license by declaring a reservation price in excess of the next highest bid.

[111] Evan Kwerel and John Williams, *A Proposal for a Rapid Transition to Market Allocation of Spectrum*, Federal Communications Commission, OPP Working Paper No. 38 (November 2002), p. 31.

In this manner, competitive market forces could both discover optimal spectrum sharing strategies including, for instance, interference temperatures and/or underlay rights. This discovery process would not abandon the rational feedback loops of consumer demand, however, and spectrum would not be allocated administratively between technologies or systems. Regulators could use such experiments to see how markets value alternative rules, technologies, and sharing arrangements. The protocols preferred by Intel could be pitted against the etiquette offered by Microsoft. Rival firms or consortia could offer standard packages, or alternatives, with consumers choosing their preferred options. This path to accommodate advanced wireless technologies, if it tests well, would merit wide adoption.

VII. CONCLUSION

The Federal Communications Commission sees that traditional regulatory structures have created bottlenecks in wireless markets, blocking the introduction of advanced technologies and leaving spectrum seriously misallocated. In some instances, policy makers have moved to substantially liberalize spectrum use, allowing markets to play the key role in determining how frequencies are utilized. The advent of exclusively-licensed, flexible-use spectrum in CMRS bands has produced enormous social value, and led to the creation of multi-billion dollar wireless networks utilizing extremely complex methods for sharing spectrum space. The success of this policy approach has been demonstrated by the consumer embrace of the services provided. Judging by users voting with their dollars, the 189 MHz of CMRS bandwidth has an estimated present value (for consumer surplus) of about $900 billion.

The Interference Temperature concept proposed by the Commission would, if applied in such bands, threaten these impressive social gains by transferring control of licensed radio space from licensees to the government. Regulators would then determine what kinds of devices could use licensed bands, on what terms, using what technologies. This would force an administrative agency to make complex choices about trade-offs involving cost, quality and service availability for users of alternative wireless systems. The market would no longer be able to competitively offer innovative solutions that clashed with government designs, nor to provide the demand, cost and profit-based feedback loops that drive private markets towards efficient solutions.

It is fitting that regulators see that existing rules limit the productivity of wireless. But the INTEM approach reverts to the planning mechanisms that have historically failed to produce social value and have blocked market innovations. When applied to exclusively-assigned, flexible-use spectrum, where those market innovations have and continue to be unleashed, it would destroy existing efficiencies.

The airwaves do not, by themselves, yield communications. Complementary inputs must be put in place to afford consumers the wireless opportunities they value. The $150 billion invested by wireless phone carriers is just a partial accounting of the economic cost of such inputs. Over-ruling the allocation decisions of the effective coordinating agents in place in that small slice of spectrum now successfully allocated to the liberalized CMRS licenses would be a highly disruptive, counter-productive approach to the problem of spectrum access for innovative technologies. Rather than leaving the "white spaces" identified by the Commission unproductive, CMRS licensees engineer systems to use every economically useful bit of space.

In fact, CDMA operators are particularly ambitious in their use of low power transmissions. CDMA chips search 800 times per second to find the lowest power levels possible for successful communications, allowing handset users to enjoy longer battery life and conserving precious bandwidth for others. The exclusivity of rights in such bands makes carriers anxious to promote additional spectrum sharing, such that operators invest aggressively to deploy new technologies (and handsets and base stations) that effectively reduce noise. To supplant these productive efforts could easily impose costs of billions of dollars annually on networks and their customers.

The underlays the INTEM Notice contemplates would favor some types of wireless systems over others, with regulators determining the extent to which the substitutions are made. By taking such decisions from the marketplace, the policy denies consumers the ability to choose among alternatives and instead imposes government's preferred solution. While unlicensed rules may leave room for rivalry within approved classes of devices, essential technology and standards issues are decided by fiat. This rules out a very substantial number of options; in general, wide area networks will be disadvantaged relative to locally used devices, despite what businesses, consumers, and suppliers might like.

The problem that the Commission seeks to solve can best be met by building on the success of exclusively-assigned, flexible use spectrum. This model has proven economically competitive against rival systems, robust across a wide range of market and technological challenges. The results of this wide experimentation ought to be central to the Commission's policy analysis here. In fact, the Commission should extend the opportunities created for licensees in the Secondary Markets proceeding. Licensees, while assuming liability for non-authorized use of devices certified to work within their bands, should be permitted to assign spectrum control to third parties without Commission approval. Given this expanded flexibility, new spectrum access models could develop.

In particular, market-based 'unlicensed' use could be accommodated. Just as customers today purchase cellphones, PDAs, or EV-DO cards with licensed spectrum access rights bundled into the sale, local network and non-network devices could be created and marketed using licensed spectrum. Then, competitive economic forces could value alternative blocks of spectrum – including underlays – by using the information provided by investors and capital markets, anticipating future purchases by customers and the technical options available, rather then relying on government regulation to determine how spectrum is utilized in the public interest.

Appendix A

Notes & Sources for Table 1

[1] Obtained from Kobb, Bennett Z., WIRELESS SPECTRUM FINDER, (McGraw Hill, 2001), *Commercial Wi-Fi Hotspots*, JUNIPER RESEARCH LIMITED (July 2003), Comments of IEEE 802, *In the Matter of Revision of Parts 2 and 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band*, ET Docket No. 03-122 (September 03, 2003), p. 7.
[2] Service revenues, equipment revenues and network capex for the 1.9 GHz band were difficult to find and assumed to be approximately zero.
[3] From *Chill Hits Wi-Fi 'Hot Spots'*, THE WALL STREET JOURNAL (March 18, 2004), p. B1.
[4] Total Equipment revenues of $4.01 billion are estimated by summing 2003 cordless phone revenues of $2.44 billion (from Kenneth R. Carter, Ahmed Lahuoji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, OSP Working Paper Series No. 39 (May 2003), p. 27) and 802.11b/g equipment revenues of $1.57 (from, *Wireless Weigh-In – 12/03*, MORGAN STANLEY EQUITY RESEARCH (December 22, 2003), p. 13). Approximately 12.5% of Wi-Fi equipment revenues accrue from public access, hence this amount is included under network capex (see Kenneth R. Carter, Ahmed Lahuoji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, OSP Working Paper Series No. 39 (May 2003), p. 33).
[5] Estimated as 12.5% of Wi-Fi equipment revenues accruing from public access (see Kenneth R. Carter, Ahmed Lahuoji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, OSP Working Paper Series No. 39 (May 2003), p. 33).
[6] Total Equipment revenues of $0.18 billion estimated using 802.11a equipment revenues, from *Wireless Weigh-In – 12/03*, MORGAN STANLEY EQUITY RESEARCH (December 22, 2003), p. 13. Approximately 12.5% of Wi-Fi equipment revenues accrue from public access, hence this amount is included under network capex (see Kenneth R. Carter, Ahmed Lahuoji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, OSP Working Paper Series No. 39 (May 2003), p. 33).
[7] Estimated as 12.5% of Wi-Fi equipment revenues accruing from public access (see Kenneth R. Carter, Ahmed Lahuoji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues*, OSP Working Paper Series No. 39 (May 2003), p. 33).
[8] Obtained from CTIA, *CTIA Semi-Annual Data Survey Results, 1985-2003*, http://www.wow-com.com/images/survey/2003_endyear/752x571/Annual_Table_Dec_2003.jpg
[9] Obtained by summing $3.6 billion and $10.2 billion spent by consumers and carriers respectively on mobile phones (From, "Phone Subsidies Alive and Well", RCR WIRELESS NEWS (January 05, 2004), p. 1).